BATHYMETRIC MAPPING USING REMOTE SENSING

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for the Degree of

MASTER OF TECHNOLOGY

by
UDAYA SINGH

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CERTIFICATE

This is to certify that present work entitled, "BATHYMETRIC MAPPING USING REMOTE SENSING" has been carried out by Mr. Udaya Singh under my supervision and is not produced anywhere for the award of a degree.

February, 1987

(Dr. K.K. Rampal)
Professor
Department of Civil Engineering
Indian Institute of Technology
Kanpur.

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ABSTRACT

Bathymetric charting and coastal mapping using MSS data are two parts that constitute this thesis work. The Landsat products such as Computer Compatible Tape (CCT), positive films paper prints were obtained from the National Remote Sensing Agency (NASA), Hyderabad. The area chosen for the study is Andhra Pradesh coastal region near Machlipatnum. The area is covered by one Landsat - 4 scene (Number : 142 : 049). The toposheets of this area having the contours of water depth of 9 m and 18 m, were obtained from Survey of India, Dehradun.

A relation is developed between reflectance value (Band and water depth. This relation has been used in preducting the water depth from reflectance value for other areas. Investigat have shown a strong correlation between Band 1 reflectance valu (MSS-Landsat 4) and shallow water depths of the sea. The prese technique enables us to get an up-to-date hydrographic informat which has been of utmost importance to navigators and coastal engineers. The bathymetric charting by Remote Sensing is not only time saving but also time effective.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The last few years have seen tremendous growth in the field of remote sensing. October 1957 marked the beginning of satellite remote sensing with the launch of SPUTNIK by U.S.S.R. For the first time in the history, a man-made object was circling the earth, covering different regions and countri of the world from its vantage point in space. This led to rap development of satellite borne sensor for reconnaissance purpo Thus remote sensing has advanced from visual analysis of aeria photographs to automatic computer analysis of digital multiba imageries. Today, one has nearly lost count of satellites tha spy the earth every moment for military and civilian purposes.

The civilian remote sensing program was essentially an U.S.A. and U.S.S.R. effort in the seventies. U.S.A. made the data available from its satellites to many countries around the world at extremely reasonable costs. As a consequence the use of such data has become common around the world. With the development of high resolution satellites like FRENCH SPOT system, remote sensing techniques are being reliably applied i large number of fields. A number of studies like crop pattern determination, crop estimation, landuse, surface water distrib river course monitoring, forestry planning, geological mapping, are being taken up.

Here in India, we have various facilities like data products laboratory at SPACE APPLICATIONS CENTRE (SAC), full-fledged acquisition and processing facility at NRSA, HYDERABAD for undertaking various projects for diverse applications. The launching of INDIAN REMOTE SENSING SATELLITE (IRS-1), which is scheduled by the end of 1987 will give the indigenous efforts a further boost in the field of remote sensing.

1.2 MULTISPECTRAL SCANNER (MSS)

The MSS oscillating mirror scans the information of the object in cross track direction and it travels along the track as shown in Fig. 1.1. It covers an area of 185 km x 185 km in one scene. The information is obtained pixel by pixel and scanned line by line. The total area of 185 km x 185 km covere in one scene is divided into 2340 scan lines and each scan line is divided into 3240 pixels as shown in Fig. 1.2, but there may be small variation in the above numbers. For the data obtained for the present investigation the number of scan lines were 2400 and number of pixels as 3238. Pixel is the minimum unit that can be distinguished from Landsat data. For MSS, the pixe has the dimensions of 57 m x 79 m.

The MSS sensor scans the data in four different bands of the optical and near IR spectrum simultaneously. The bands ar numbered as 4, 5, 6 and 7 in Landsats 1, 2 and 3 and as 1, 2, 3 and 4 in Landsats 4 and 5. Each one of the band is useful for

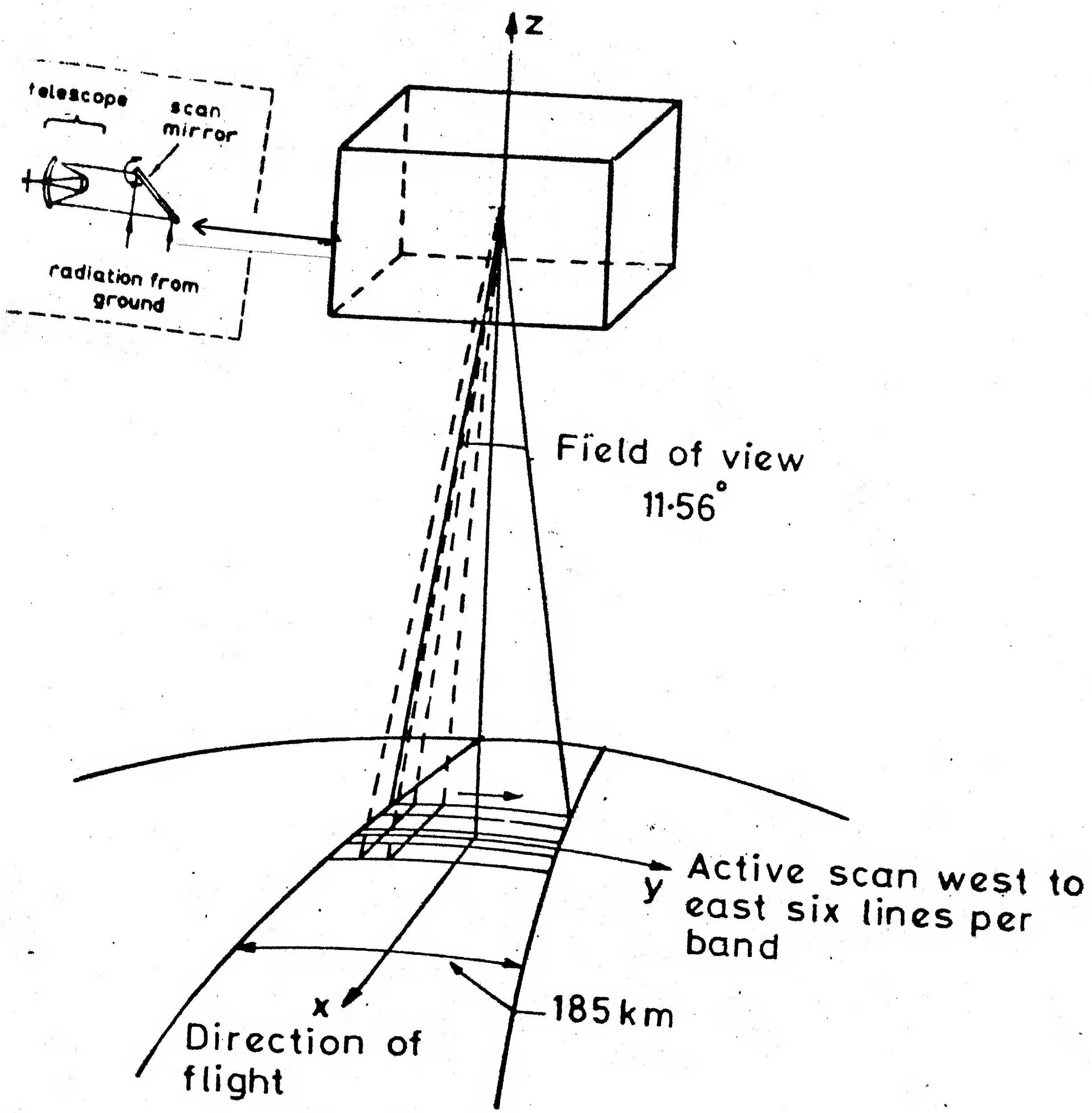


Fig. 1.1 Multispectral scanner

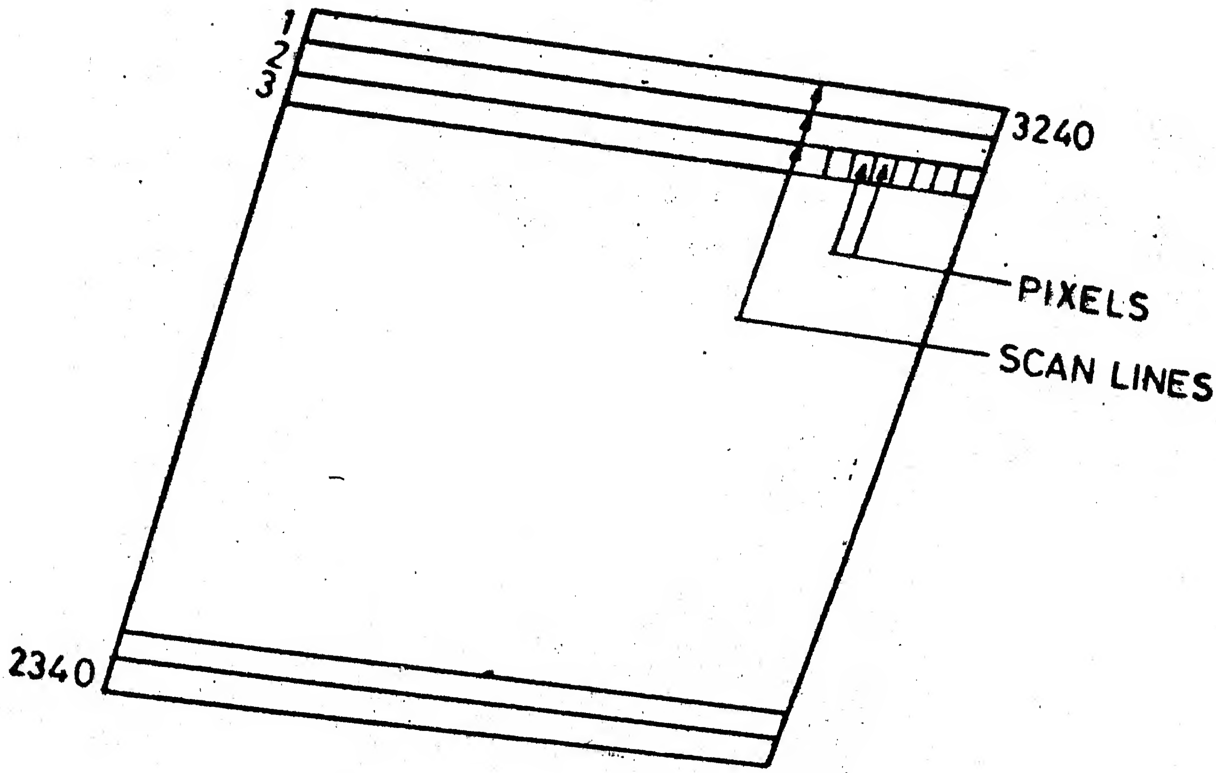


FIG 1.2 SCAN LINES AND PIXELS IN A SCENE

one particular field of study. The various uses of each band are given in Table 1.1.

1.3 THEMATIC MAPPER (TM)

It is a special scanner which has better resolution than MSS and operates in 7 channels. Various bands are numbered as 1 to 7 and each one has application in a specific field of study. All the channels have a spectral resolution of 30 m against the 79 m in MSS, except for thermal band i.e. band 7. The various bands and their uses are given in Table 1.1

1.4 APPLICATION OF REMOTE SENSING

Remote Sensing has proved its worth in various applications. Indian scientists at various well equipped research organisations and frontline academic institutes have applied the satellite products for diverse applications like geological, agricultural, landuse with diverse techniques like computer aided, visual and image processing.

Snow melt run-off studies (Ramamoorthi, 1983), ground water table prediction (Rampal, 1984), soil mapping (Karale, 1983), forest survey and management (Madhavan Unni, 1983) land evaluation and classification for agriculture (Murthy,

TABLE 1.1 : SPECTRAL BANDS AND SIGNIFICANCE

SENSOR	SPECTRAL BANDS	RESOLUTION	APPLICATION
LANDSAT-MSS			
BAND - 1	0.5 - 0.6 um	80 m	Qualitative discrimination of depth and turbidity of standing water bodies.
BAND - 2	0.6 - 0.7 um	80 m	Delineation of topographic and cultural features.
BAND - 3	0.7 - 0.8 um	80 m	Shows tonal contrasts for various land-use categories.
BAND - 4	0.8 - 1.1 um	80 m	Land-water discrimination.
LANDSAT THEMATIC MAPPER			
BAND - 1	0.45 - 0.52 um	30 m	Increased penetration into water bodies, soil/vegetation and deciduous/coniferou flora discrimination.
BAND - 2	0.52 - 0.60 um	30 m	Vegetation, vigor assessment
BAND - 3	0.63 - 0.69 um	30 m	Chlorophyl absorption band for vegetation discrimination, for contrast between vegetation and non-vegetation features.
BAND - 4	0.76 - 0.90 um	30 m	Biomass content and delineating water bodies.
BAND - 5	1.55 - 1.75 um	30 m	Vegetation/soil moisture content and snow/cloud differentiation.
BAND - 6	2.08 - 2.35 um	30 m	Discriminating rock types and hydrothermal anomalies.
BAND - 7	10.40 - 12.50 um	120 m	Thermal IR band for vegetation stress, soil moisture and thermal mapping.

Venkataratnam and Saxena, 1983) are few to quote among Indian works.

1.5 CRITERIA FOR THE SELECTION OF BAND

It is very important to select a suitable band for a given field of study. The criteria for the selection are as follows.

The imageries which are available in Band 1, 2, 3 and 4 differ in appearance which depend upon the varying reflectance of the different features of the earth's surface. Maximum transmission of light in clear sea water is in the blue spectral region. Water acts as an optical filter, progressively absorbing radiant energy at longer wave lengths until almost complete absorption occurs in the near infrared region. It is shown in Fig. 1.3.

Shallow clear water or water containing suspended materials returns considerable amount of light in less attenuated Band 1 which provides valuable information regardi the depth or nature of foreshore and bottom, concentration of

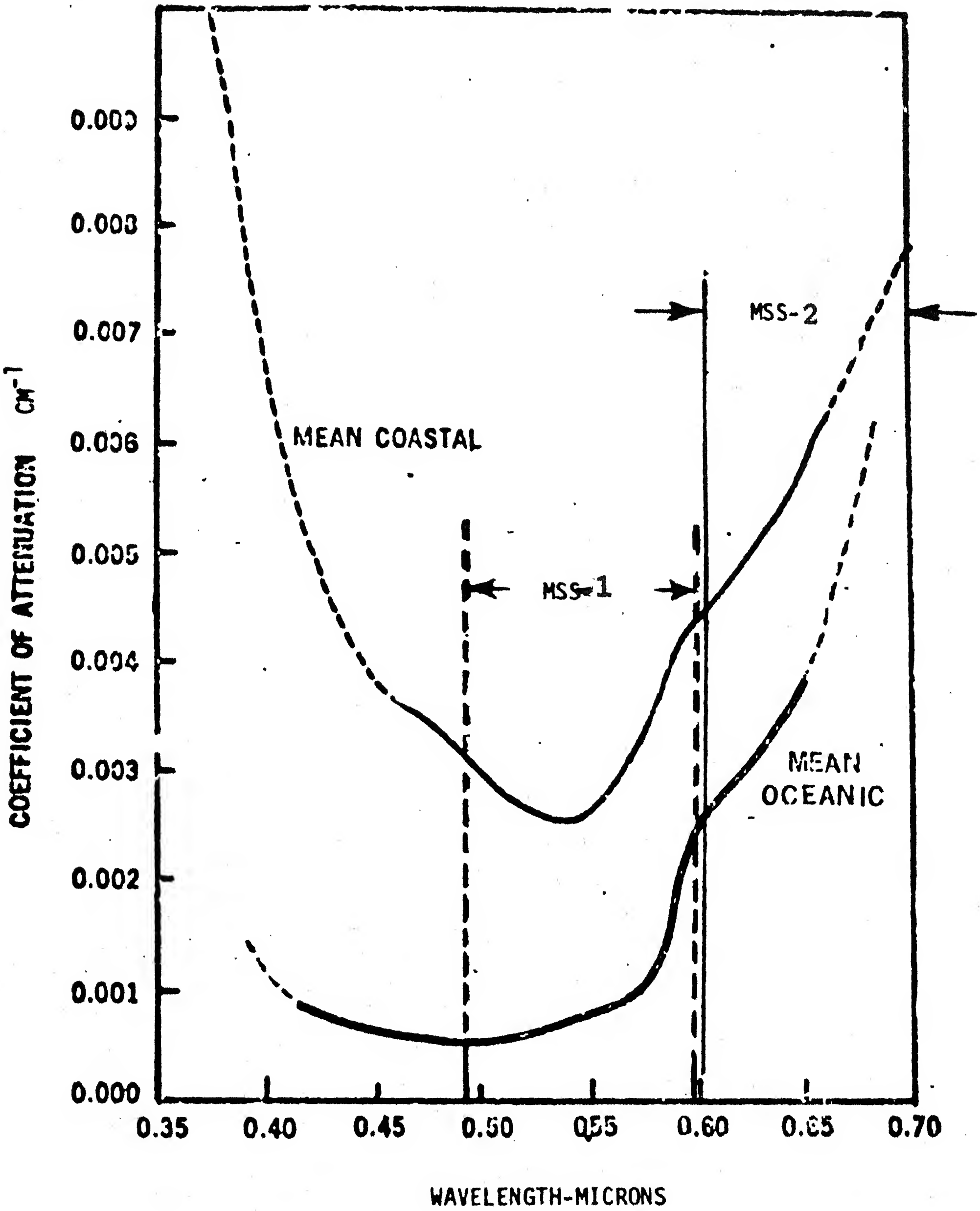


Fig. 1.3: Light Attenuation in Ocean Water in Band - 1 and Band - 2.

suspended material, location of submerged objects.

The attenuation coefficient is higher in band 2, 3 and 4 and very little light is directed towards satellite by water bodies which appears very dark as compared to land surfa Therefore, long wavelength bands particularly band 4 is very useful in distinguishing land from water and are helpful in delineation of coast line, islands, sandspits etc.

Hence for the present work, band 1 was selected for determining water depth and band 4 was selected for mapping th land and water.

1.6 NEED OF REMOTE SENSING FOR HYDROGRAPHIC SURVEYING

A study of the hydrographic surveying reveals that except for the extremely small area (5%) surveyed, the remaining areas have been inadequately surveyed, which constitute enormous surveying task. The 1982 Expert Group Report on Hydrographic Perspective Plan has assessed that it would take a span of 10 years by employing 16 surveying vessel and over 4500 personnels to complete navigational surveys and present strength of survey vessels and manpower is deficient. Apart from this, the coastal areas and mouths of rivers on eas coast of India like Hugli, Mahanadi, Godavari, Krishna are changing frequently due to floods and storms. The position, extent and depths of many offshore islands, banks, shoals etc.

which are not connected with main land by triangulation are required to be determined. Some ships require navigable area which are more than 22 m deep. An up-to-date hydrographic information has always been of utmost importance to navigators and coastal engineers.

The hydrographers have traditionally relied on sounding machine, echo sounding and aerial photography to maintain and update their nautical charts. Though these inventory technique are quite effective and recent but are slow, cumbersome and costly. At the same time catastrophic events like floods, storm can change the hydrography quickly in delta regions, sandy shore etc. Therefore, the hydrographer requires a method which can give him quick results on bathymetry, coastline, shoals etc. which he is unable to get by conventional method, without losing much time.

In the continued attempt to introduce advance technology fitting to the navigator's requirement attempts have been made to develop the new method of collecting offshore hydrography through remote sensing techniques. This method has greatly reduced the cost and improved the quality of work. This has great potential to collect large amount of hydrographic data very rapidly over shallow coastal water.

In this present project, an attempt has been made to correlate the reflectance of water bodies obtained by sensor and water depth for shallow water. We have prepared the map of coastal area distinguishing land, clear water and water having suspended materials. Our area of study in Andhra Pradesh coastal area between Madras and Kakinada. Details of the study are explained in the following chapters.

1.7 OBJECTIVE OF THE STUDY

The objective of the study is:-

(1) to correlate the reflectance (MSS Band 1) with shallow water depth

(2) to map the coastal area distinguishing land, water having suspended materials and clear water.

To achieve the first objective of the work, it is necessary to get water depth contours of that area, to calcul the latitudes and longitudes of the points on the known water depth contours, to convert these coordinates to line numbers and pixel numbers and to read the corresponding reflectance values from CCT obtained from NRSA in MSS Band 1. The procedure for this work is given in chapter 3.

For the second objective an area, which covers the land, water containing suspended materials and clear water, was chosen on imagery and reflectance values of all the pixel falling over that area were read from CCT. Maps were prepare by the program which is given in Appendix 6.

CHAPTER 2

SCOPE OF THE WORK

2.1 EARLIER STUDIES

Not much literature is available on the application of Remote Sensing in the field of measurement of water depth. Bathymetry is very old field for navigators and they are usinc so many traditional methods of water depth measurement like sounding machine, echosounding, aerial photography etc. Thouc these techniques are quite effective but are slow.

The work of Ross(2) and Polcyn and Rollin(8) have shown that there is a correlation between MSS band 1 imagery a shallow water depth. Correlation was found between MSS - 1 imagery and depth in number of areas corresponding to water depth of less than 2 m, 5 to 10 m. But the depth predicted from imagery was approximate. Under favourable condition Landsat imagery can detect sub-surface detail as small as 200 in diameter. Water depth over a large area of world coastline and shallow sea can be assessed by Landsat imagery and image processing technique which would be valuable aid to chart revision by directing the hydrographer to area requiring close examination.

The wave refraction method was applied by Polycn in 1969. The underlying principle in this case is that when a wave moves through a liquid the characteristics of the medium which may influence its motion are:-

(a) The depth and other boundary conditions.

(b) Gravitation, since the changed profile or contour of the surface involves work against gravity.

(c) Surface tension, because the pressure under a curved surface is different from that beneath a flat surface.

(d) Viscosity, which is the dissipative energy agent.

The velocity of propagation for a surface wave in a liquid of density ρ is given by

$$v^2 = \frac{2\pi S}{\rho\lambda} + \frac{g\lambda}{2\pi} \qquad (2.1)$$

where S = surface tension

g = acceleration due to gravity

λ = wave length

For sufficiently large value of λ i.e., for long waves first term is negligible compared to second term of the above expression. Thus the velocity of 'Gravity Waves' is given by

$$v^2 = \frac{g\lambda}{2\pi}$$

These gravity waves are observed over deep part of the water body. We know that

$$v = f\lambda$$

where, f = frequency of wave.

Since time period of a wave is the inverse of the frequency i.e. time period (p) = $\frac{1}{f}$

Finally we get the relation between velocity and time period as

$$v = \frac{\lambda}{p} = 5.09 \, p$$

where g = 32 ft./sec^2

v being measured in ft./sec.

The velocity in the shallow water is given by the expression

$$v^2 = gd \qquad (2.2)$$

where v = velocity of the wave

g = gracitational acceleration

d = depth of water.

As the wave moves from deeper portion to the shallow part, the time period of the wave 'p' remains constant. This property is utilized to determine the depth. If v_o be velocity for deep water, then we have

$$v_o^2 = \frac{g\lambda_o}{2\pi} = (f_o\lambda_o)^2 = \frac{\lambda_o^2}{p^2}$$

where f_o = frequency of wave in deep water

λ_o = wave length in deep water

p = time period of wave = $1/f_o$

Therefore, $$p^2 = \frac{2\pi\lambda_o}{g} \qquad (2.3)$$

For shallow water

$$v^2 = gd = \frac{\lambda^2}{p^2}$$

Therefore, $$p^2 = \frac{\lambda^2}{gd} \qquad (2.4)$$

Now from equations 2.3 and 2.4, we get

$$\frac{\lambda}{\lambda_o} = \frac{2\pi d}{\lambda} \qquad (2.5)$$

and also $$\frac{v}{v_o} = \frac{\lambda}{\lambda_o}$$

The ratio $\frac{\lambda}{\lambda_o}$ is thus functionally related to the ratio $\frac{d}{\lambda}$

A measurement of λ_o & λ will then allow 'd' to be determined. This can be done by successive picture at short intervals to obtain the values of v_o & v. Measurement of λ_o can be made directly from an aerial photograph. This method can, therefore, be applied easily where seashore or the bed of the water body slopes gently.

Polcyn & Lezenga [3] demonstrated the use of satellite data for mapping of shallow water features for the purpose of upgrading the world navigation charts. A mathematical model for depth measurement using the ratio of reflectance in Band 1 and Band 2 had been successfully developed. Satellite data also provide geographical evidence for verifying existence or non-existence of doubtful shoal features appearing in the world charts and considered to be hazardous to shipping.

The technique employs the relation shown by equation

$$Z = \frac{1}{f(\theta, \phi)\,(K_1 - K_2)} \ln \frac{\alpha_1 V_1 H_1 \rho_1}{\alpha_2 V_2 H_2 \rho_2} \qquad (2.6)$$

Where Z = water depth.

K_1, K_2 = attenuation coefficients of water in two different wave lengths.

ρ_1, ρ_2 = reflectances for bottom material in two different bands.

α_1, α_2 = constants of instrument which are known.

H_1, H_2 = incoming solar radiations.

V_1, V_2 = analog signals observed in the multispectral scanning.

θ = observation angle.

ϕ = solar zenith angle.

Here V_1 and V_2 are obtained from Band 1 and Band 2 of CCT. The incoming solar radiation (H_1, H_2) is available from standard references. ρ_1 and ρ_2 are reflectances for bottom materials, which are known.

Photogrammetric bathymetry is one of the traditional techniques of remote bathymetry. Colour aerial photography with its remarkable clear water penetration characteristics and dramatic presentation of submerged detail is basic tool in this method for mapping seabed in water of moderate depth. Aerial photogrammetry of bathymetry requires several minor departures from the method normally used where bundle of light rays passes only through atmosphere. The effect of refraction at the water air interface must be taken into account in the aerotriangulation for imaged point. The solution of this problem requires a mathematical model for two media refraction.

To get correct and entirely acceptable for photogrammetric trangulation, the mathematical modelling must be based upon the actual under water position of the point rather than its refrected

or apparent position. The basic mathematical model for correctir image coordinates of under water points is illustrated in Fig.2.1

$$\Delta d = d.h\,(1 - 1/a)/(H - h) \qquad (2.7)$$

where Δd = the correction in meters for image point. Its sign is always negative (correction towards the photocentre).

d = radius of image point in the form $(x^2 + y^2)^{\frac{1}{2}}$

h = depth in meters of the underwater point at the time of photography.

H = flying height in meter.

a = ratio of tangents of angles of refraction(r) and incidence (i).

i.e. $$a = \frac{\tan r}{\tan i} = [\mu^2 + (\mu^2 - 1)\tan^2 r]^{\frac{1}{2}}$$

where, $\tan r = \dfrac{d}{f}$, for vertical photograph.

μ = index of refrection for ray passing from water to ai

f = camera focal length in meters.

If $\mu = 1.34$

$$a = [1.7956 + (0.7956)\, d^2/f^2]^{\frac{1}{2}} \qquad (2.8)$$

The relation between refraction corrected coordinate value

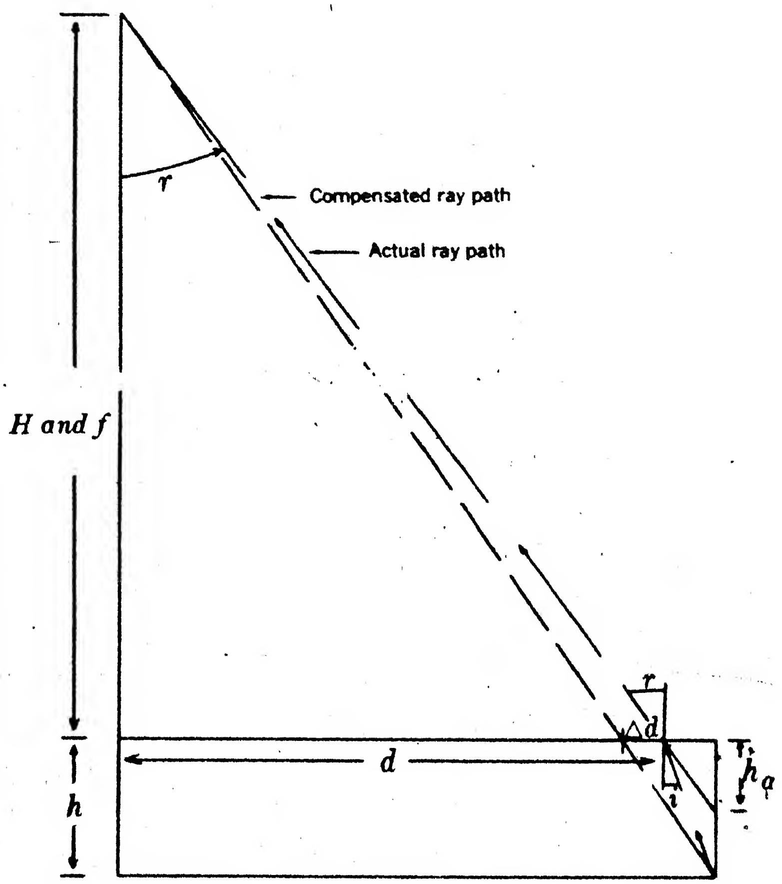


Fig.2.1: Image Displacement due
Water Surface Refraction

(x', y') and the photo image coordinate (x, y) is shown below

$$x' = x(1 - \Delta d/d)$$

$$y' = y(1 + \Delta d/d) \qquad (2.9)$$

The change in the value of equation (2.8) and its effect on Δd caused by 1° or 2° tilt is insignificant in aerial photograph if H is greater than 100 h. Therefore, the refrection compensated coordinates of all the vertical control point can be determined. To be theoretically correct, the unknown depths (h) of the test point should be solved as additional unknown in the aerotriangulation process using equation (2.7) through the iterative process.

Moore (1947) developed a transparency method for water depth from aerial photography alone. This was one of the first remote sensing method. Basically the method consists of determining the optical extinction coefficient of the water column from the brightness measured at identical points in two specially filtered (red and green) photographs. The spot depths are determined by means of a ratio calculator which compares the brightness in two band to know water colour-transmission. Results with ± 10% accuracy to a depth of about 6 m are achieved over homogeneous san bottoms. This technique is limited to calm sea, relatively clear water, bright skies, without cloud patterns and sun angle between 30° and 55°.

2.2 AREA UNDER STUDY

From the work of Ross[2], Polcyn and Lyzen[3], Jha and Satya Prakash[5] and others it is clear that MSS band 1 reflectanc values could be used to predict shallow water depth. Satisfying above condition, coastal area of Andhra Pradesh was selected. The area is along the east cost of the Andhra Pradesh region between Madras and Kakinada.

The area is covered by one Landsat - 4 scene. For reference the index map of Landsat - 4 coverage is shown in Fig.2. The index map is supplied by NRSA. Any scene is located by Path number and Row number. The area selected is located by Path number - Row number : 152 - 049. The area inclosed by the longitudes and latitudes is shown in Fig. 2.3.

2.3 DATA COLLECTED FOR THE WORK

The data collected for the work are as follows:

(1) Landsat data.

(2) Topo sheets with water depth contours.

The Landsat data in the form of CCT containing reflectance values for band 1, 2, 3, 4, positive films(1 : 1 M) and paper print (1 : 1/2 M) were obtained from NRSA, Hyderabad, While selecting

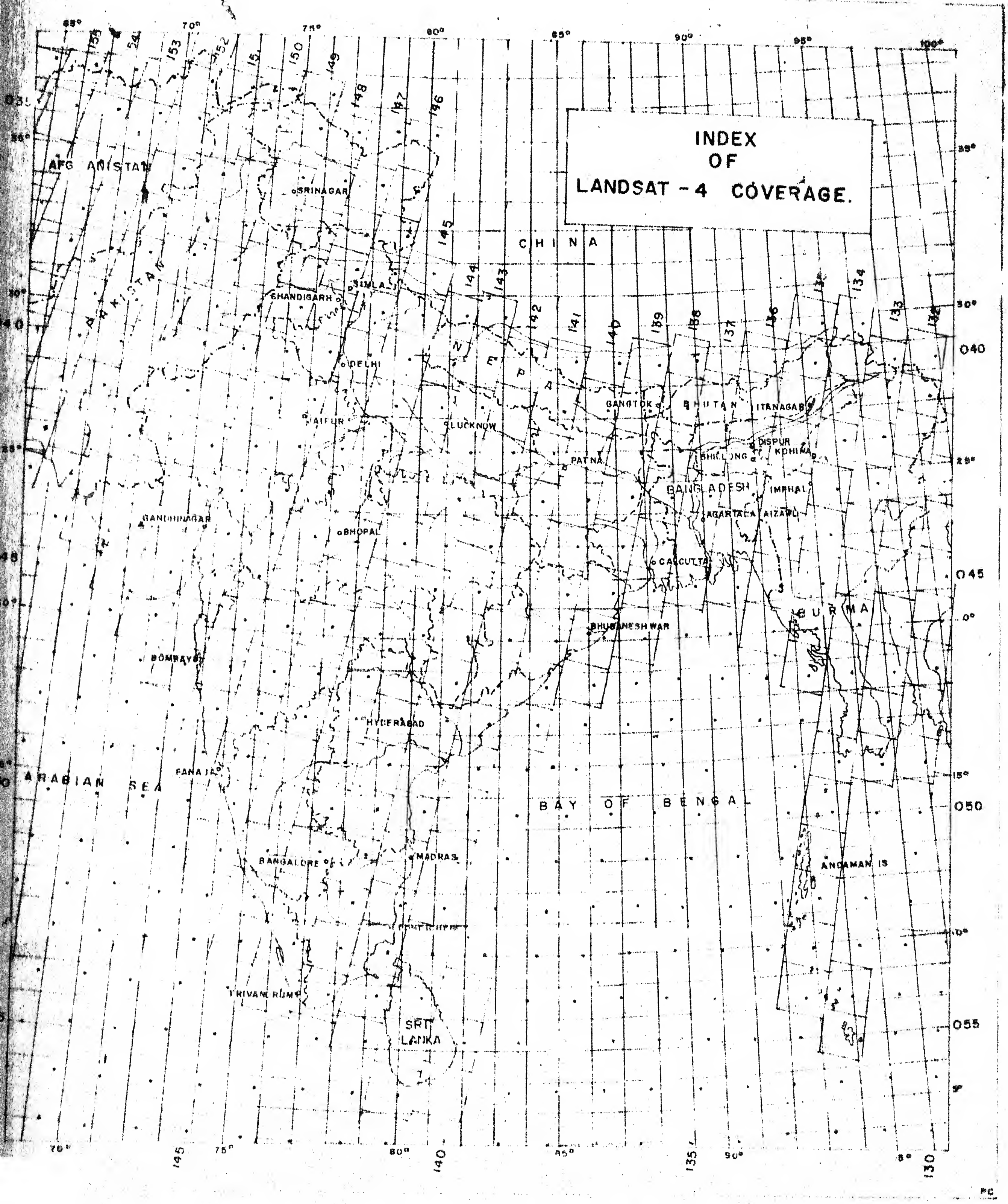


Fig. 2.2: Index Map of Landsat 4 Coverage
(Supplied by NRSA)

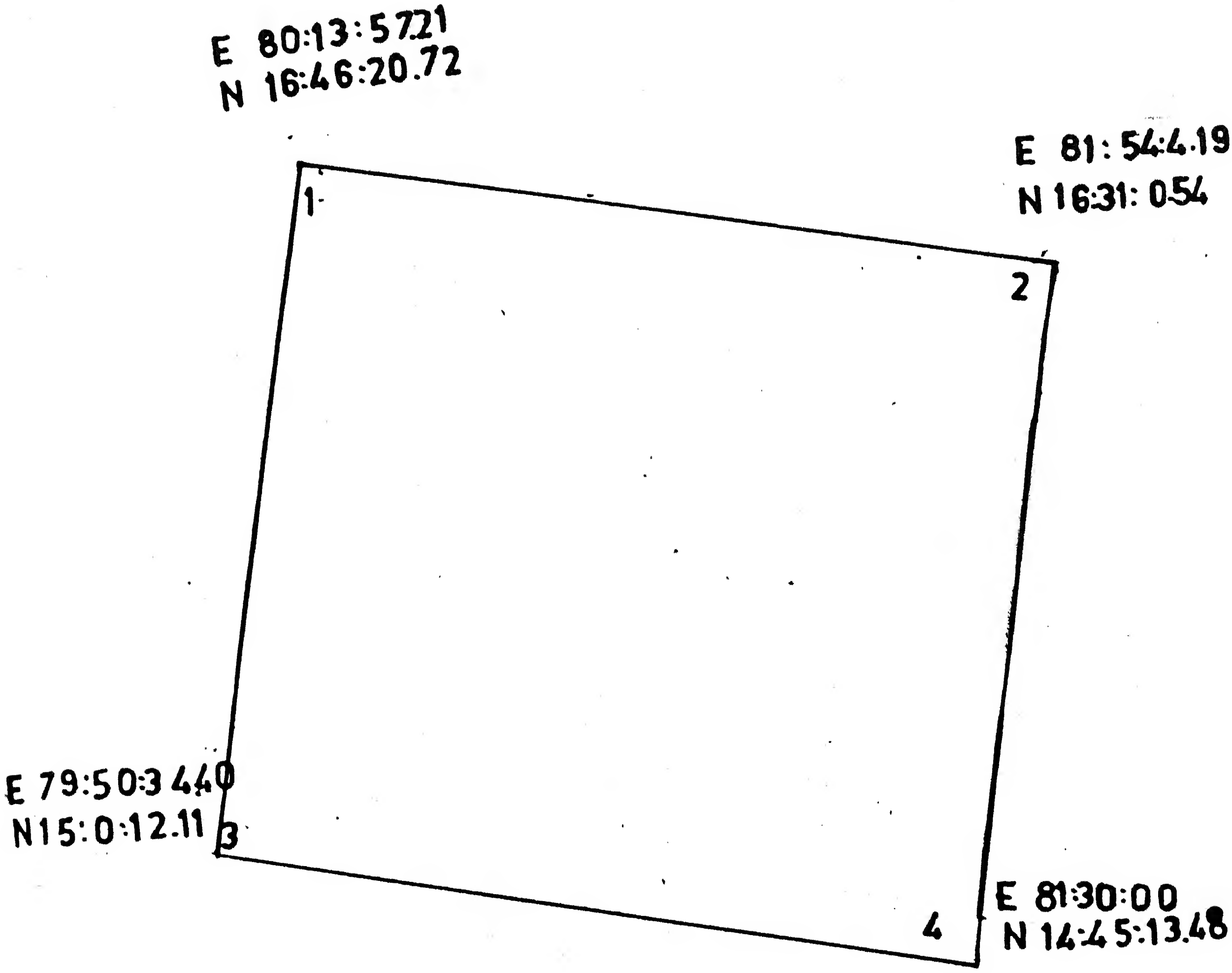


FIG 2.3 AREA UNDER STUDY

the date of pass, for which Landsat data is obtained care is exercised so that there is no cloud cover. The date of pass for present data is for 28th September 1983.

The toposheets of the area were obtained from SURVEY OF INDIA. The area is covered by two toposheets of scale 1:250,000 (1 : 1/4 M). With reference to index map of Survey of India, the two maps are designated as 66 A & E and 65 H. To obtain the information about availability of map of required scale, costs, whether restricted or not one may write to MAP SCALES OFFICE, HUDA COMPLEX, TARNAKA, HYDERABAD. On these two toposheets itself, the two water depth contours of 9 m and 18 m are shown.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

To obtain the reflectance value of a ground point, it is necessary to convert the longitude and latitude of that ground point to corresponding line number and pixel number. For this it is necessary to determine all the corner coordinates of the imagery very precisely. The corner points coordinate are as shown in Fig. 3.1.

3.2 CONVERSION OF GEOGRAPHICAL COORDINATE TO CONICAL ORTHOMORPHIC COORDINATE

Projection of geographical coordinates of Landsat imagery, which is on curved surface is to be converted to a flat surface whose X and Y coordinates can be computed. This map projection used for this purpose is the conical orthomorphic projection which is used country like India to minimize projection distorti

The orbit of Landsat makes an angle about 9° with the North direction. Hence the edges of image are not parallel

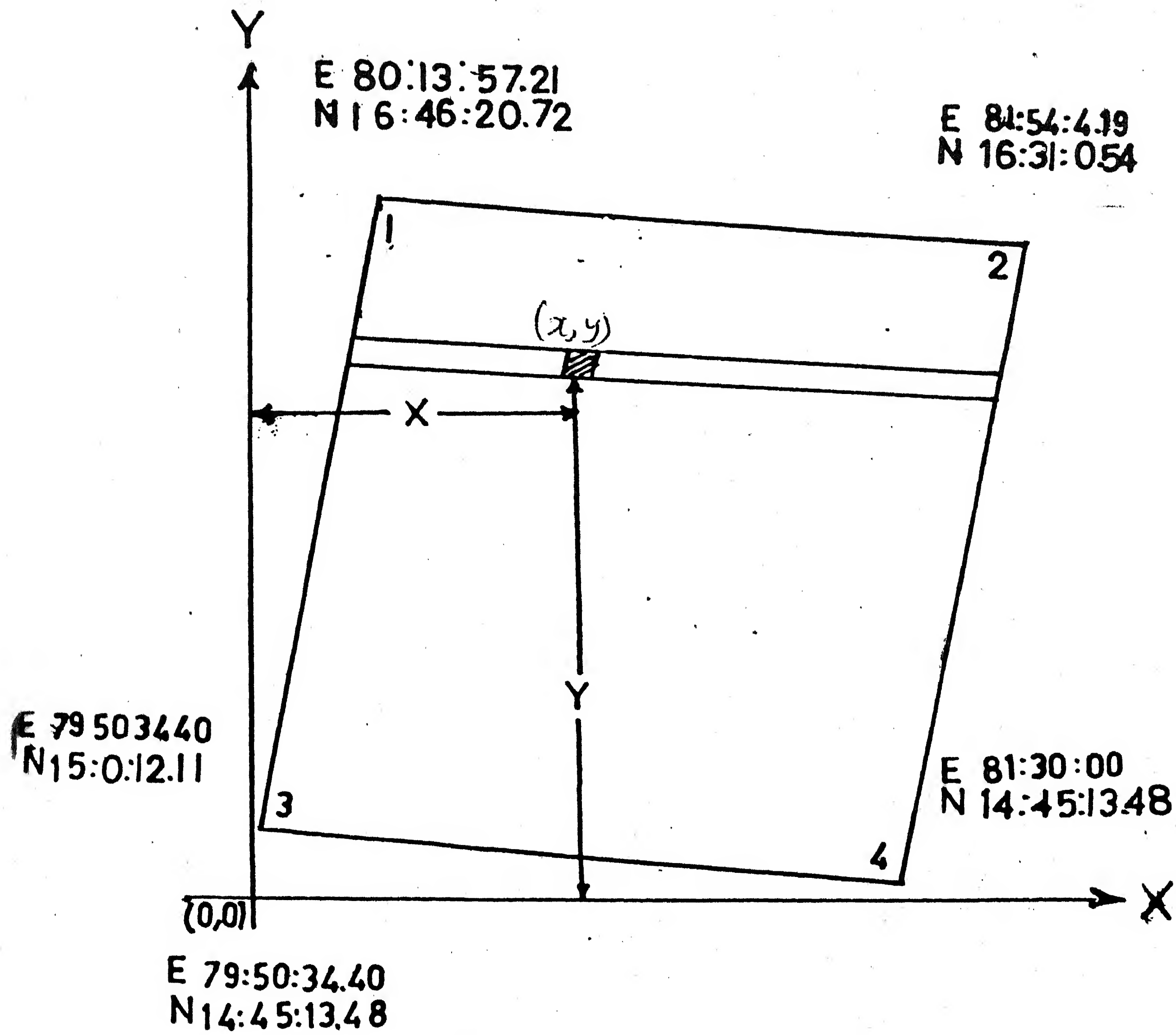


FIG 3.1 CORNER COORDINATES OF IMAGE AND CONVESION TO LINE NO. AND PIXEL NO.

to the longitude lines. The geographical coordinates of the corner points are converted to conical orthomorphic coordinates with reference to chosen coordinate axis system parallel to longitude and latitude. The origin is chosen to be a point just outside the imagery preferably just below it and slightly towards the left so that no coordinates (X, Y) become negative as shown in Fig. 3.1.

For the conversion of geographical coordinates to conical orthomorphic coordinates, latitudes and longitudes of the four corners of imagery should be precisely known. These value can be obtained from the records published by the Eros Data Centre, Sious Falls, South Dakota (The center supplies Landsat-imageries and Tapes on a world-wide basis). Fig. 3.2 represents the four corners of the imagery. The origin O is chosen to be point outside the imagery as reference point. Let the origin O has geographical coordinates (ϕ_o , L_o) where ϕ_o is latitude and L_o is longitude. Again let (ϕ_p, L_p) be geographical coordinates of any point on the imagery. The conical orthomorphic coordinate can be given as:-

$$X = (P - m') \sin\gamma$$

$$Y = m' + X \tan (\frac{\gamma}{2})$$

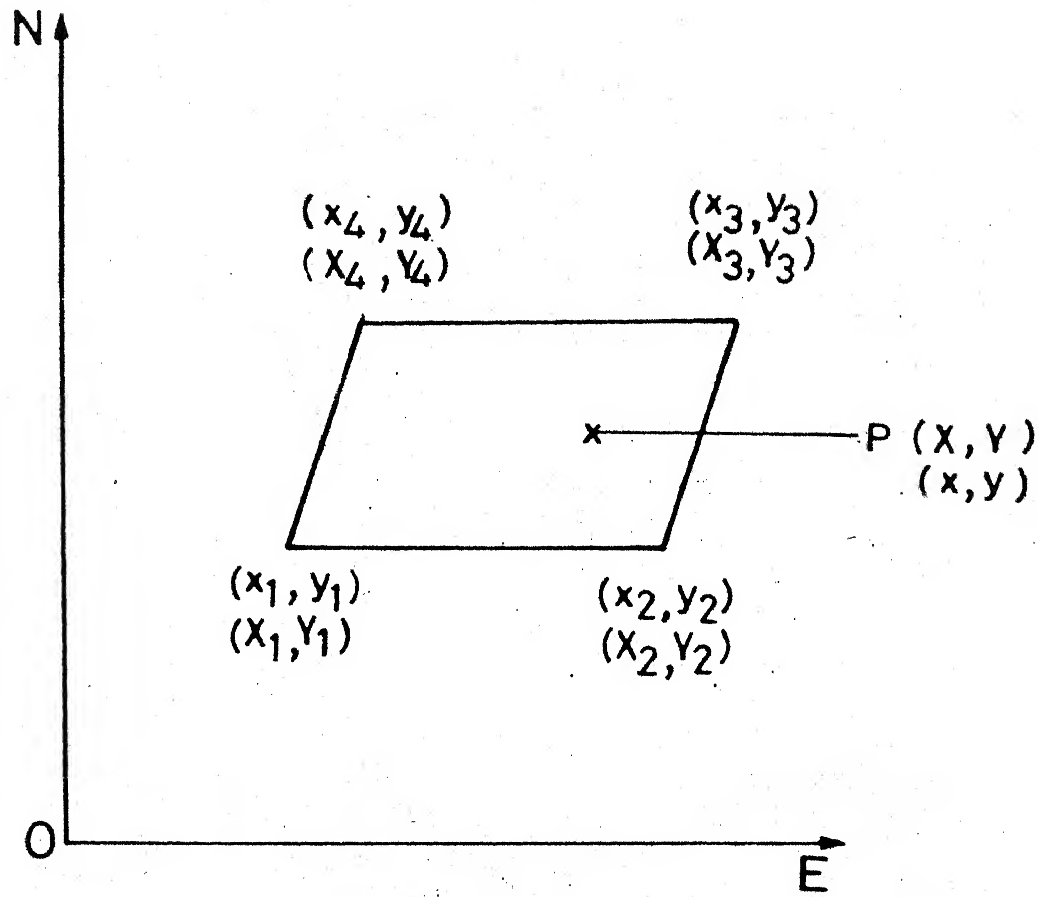


Fig. 3.2 Transformation of geographical co-ordinates to conical orthomorphic co-ordinates

where, $\gamma = \Delta L \sin\left(\frac{\phi_o}{2}\right)$

$$\Delta L = L_p - L_o$$

$$m' = m + \frac{m^3}{6R_oN_o} + \frac{m^4 \tan \phi_o}{24\, R_oN_o^2} + \frac{m^5(5 + 3\tan^2 \phi_o)}{120\, R_oN_o^3}$$

R_o = Radius of curvature of the earth (Meridianal)

$$= \frac{a(1 - e^2)}{(1 - e^2\sin^2\phi_o)^{3/2}}$$

a = major axis of the reference ellipsoid

= 6377277.6 m (For Everest Ellipsoid adopted for India)

b = minor axis of the reference ellipsoid.

= 6356075.0 m (For Everest Ellipsoid adopted for India)

e^2 = eccentricity = $1 - b^2/a^2$

For the Everest Ellipsoid, $e = \frac{1}{300.8}$

N_o = normal to the surface at ϕ_o (Normal section radius)

$$= \frac{a}{(1 - e^2\sin^2\phi_o)^{\frac{1}{2}}}$$

$$m = R_m(\phi_p - \phi_o)$$

$$P = N_o \cot \phi_o$$

R_m = Mean radius of the earth (Normal section radius)

$$= \sqrt{N_o R_o}$$

A program to calculate the conical orthomorphic coordinate of a point given its longitude and latitude is given in the Appendix - 1.

Here origin of the reference axis was taken just below the third corner point and has its coordinate E 79° 50' 34.40", N 14° 45' 13.48". The corner points 1, 2 and 3 were converted to conical orthomorphic coordinates. The conversion results are shown in Table 3.1.

3.3 CALCULATION OF THE CONSTANT OF THE AREA

Transformation from conical orthomorphic coordinate to line number and pixel number can be made by the following equations.

$$X = A_1 x + B_1 y + C_1$$

$$Y = A_2 x + B_2 y + C_2$$

where X = conical orthomorphic coordinate of the point: Longitude

Y = conical orthomorphic coordinate of the point: Latitude

x = Line number

y = Pixel number

TABLE 3.1

CONVERSION OF CORNER COORDINATES

Corner Point	Geographical coordinate		Conical orthomorphic coordinate	
	Longitude	Latitude	Longitude (X)	Latitude (Y)
1.	80.232558	16.772421	41552.5824008	224769.6131003
2.	81.901163	16.516816	219743.0386210	197273.3419803
3.	79.842890	15.003363	0.000	27783.9174497

Now we have six equations and six unknowns A_1, B_1, C_1, A_2, B_2 and C_2. These six simultaneous equations were solved and unknowns were determined.

The calculated values of the constants are:-

A_1 = -17.32079300

B_1 = 55.04802500

C_1 = 41514.855000

A_2 = -82.111587

B_2 = -8.4943687

C_2 = 224860.220000

A_1, B_1, C_1, A_2, B_2 and C_2 are constants whose values can be determined from a minimum of three ground points. The three points chosen are three corners of the imagery whose (x, y) coordinates are already computed from early transformation from their geographical coordinates. The (x, y) coordinate (line number and pixel number) of these three points are also known, since they are corner of the imagery. The set of equations are:

$$X_1 = A_1x_1 + B_1y_1 + C_1$$

$$Y_1 = A_2x_1 + B_2y_1 + C_2$$

$$X_2 = A_1x_2 + B_1y_2 + C_1$$

$$Y_2 = A_2x_2 + B_2y_2 + C_2$$

$$X_3 = A_1x_3 + B_1y_3 + C_1$$

$$Y_3 = A_2x_3 + B_2y_3 + C_2$$

Here suffixes 1, 2 and 3 refer to corner points 1, 2 and 3.

3.4 DETERMINATION OF LINE NUMBER AND PIXEL NUMBER

Now the line number and pixel number of any point on the imagery can be found by solving the two simultaneous equations

$$X = A_1x + B_1y + C_1$$

$$Y = A_2x + B_2y + C_2$$

Here A_1, B_1, C_1, A_2, B_2, C_2, X and Y are known and x and y can be calculated. A program for solving these equations thereby determining the line number and pixel number of any point on the imagery is given in Appendix - 2.

By giving geographical coordinate in degree, minute and second, the program calculates the line number and pixel number of any point within that area.

The scale of toposheets is 1:250,000. The latitude and longitude of all the necessary points was determined precisely with toposheet.

3.5 READING THE COMPUTER COMPATIBLE TAPE (CCT)

The input data for the present study were taken from CCT. Each pixel is encoded in a byte on the CCT. Each byte is composed of eight binary digits (bits) which are arranged to represent different brightness value as binary number.

The data is stored in CCT in three files; 1st and 2nd files being Tape Directory and Header Record respectively. The tape directory identifies the contents, format of CCT etc. The header record givesthe content of data and discribes the format

in which the data are recorded. Third file contains the data in four bands. Third file consists of 9600 records and each record contains 3596 bytes. Each record in third file represents one scan line in one band. Each scan line requires four records to be completely described in all four MSS bands. The mode of data storage is Band-Inter-Leaved (BIL). In this type of data storage, first four records correspond to scan line number 1. One for each band i.e. first record gives the data for line number 1 in band 1, second records gives the data for line number 1 in band 2, third records gives the data for line number 1 in band 3 and fourth record gives the data for line number 1 in band 4. Fifth record to eighth record corresponds to scan line number 2 in all four bands, i.e. fifth record corresponds to band 1, sixth record corresponds to band 2 and so on. So in this tape, to get the data of xth line in band 4, one has to read '4x'th record. In each record before and after the data, there are zero fills. The number of zero fills varies from record to record. If there are n initial zeros in the record and if we want the reflectance value of Nth pixel, then we have to read the reflectance value of $(N + n)^{th}$ pixel (Byte).

The CCT used in DEC-10 system has 9 tracks. A frame consists of bits 0 to 7 in which the pixel brightness is recorded and a ninth parity bit. A word is made of 4 bytes or

36 bits. This is shown in Fig. 3.3.

A program for reading CCT is given in Appendix - 3. This program reads one scan line in one band of the image file. The CCT as obtained could not be read on DEC-10 system. This is because DEC-10 is 36 bits word machine and CCT is formated for 32 bits word machine. If one tries to read the CCT as obtained the DEC-10 system will not read the 5th, 10th, 15th.........bytes due to lack of compatibility between the tape format and DEC-10 system. A dummy blank was introduced after 4th, 9th, 14th.......bytes increasing the record size from 3596 bytes to 4500 bytes. When the tape is read on DEC-10 system, the introduced dummy blank bytes will be skipped and data of all 3596 bytes will be printed.

The required record number to be read, is found by multiplying the line number with 4 and adding the band number. All the record numbers are stored in the increasing order and CCT is read record by record. To get the reflectance of a pixel, the number of initial zeros are counted in each of the record and added to pixel number to get the byte number corresponding to that pixel and the reflectance value is read from CCT for that byte.

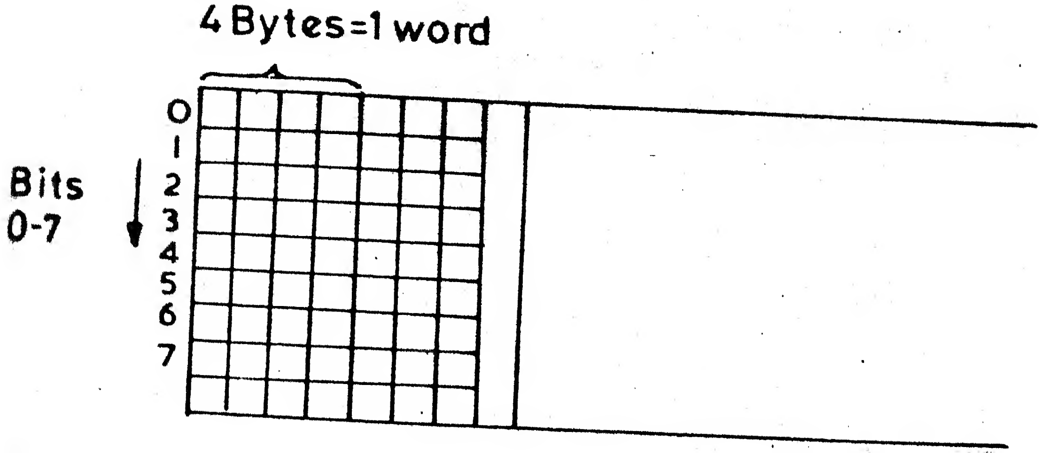


Fig. 3.3 Cross section of a 9 track CCT

CHAPTER 4

NUMERICAL RESULTS

4.1 RELATION BETWEEN REFLECTANCE VALUE AND WATER DEPTH

In water area, the light reaches back to MSS (sensor) as reflection from water surface, scattering directly in atmosphere, reflection from bottom (seabed) and reflection or scattering from the object inside the water. Scattering directly from atmosphere and surface reflection is same for same condition. But reflection from bottom is affected by suspended material which can scatter the light. The amount of light returned from the bottom depends upon the depth of water, its attenuation coefficient for the wave length and reflection coefficient of the bottom. The light reaching the bottom is also affected by the slope angle E' which can be calculated, if refractive index of sea water is known. Light path from sun to satellite is shown in Fig. 4.1.

For water depth d, the optical path length in water

$$= d(1 + \operatorname{cosec} E') \tag{4.1}$$

If μ is refractive index of sea water then

$$\mu = \frac{\sin (90^\circ - E)}{\sin r} \tag{4.2}$$

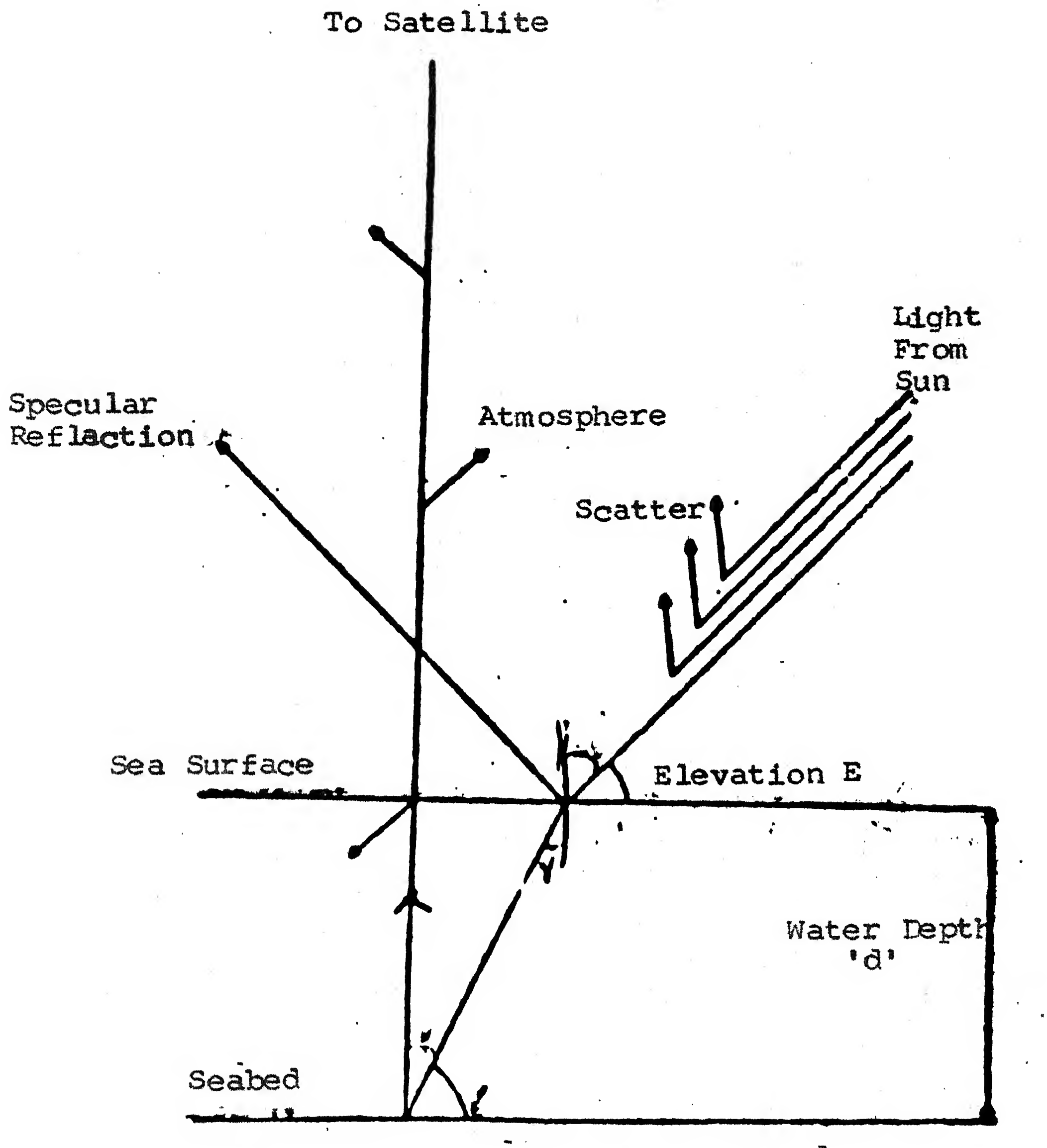


Fig. 4.1 : Light Paths From Sun to Satellite

where, E = sun elevation

$$r = \sin^{-1} \left(\frac{\cos E}{\mu}\right) \quad (4.3)$$

$$E' = 90° - r \quad (4.4)$$

Here $E = 55°$ and $\mu = 1.34$

Therefore $E' = 64° \; 39' \; 23''$

The value of sun elevation E, is given in imagery of study area. When light passes through a distance dL in water, then energy is attenuated to an amount dE, which is proportional to the energy E and the distance dL

$$\text{or} \qquad dE = -K.dL.E \quad (4.5)$$

where K = attenuation coefficient and is dependent on wave length. The negative sign indicates loss of energy. If E_o and E_L be energy of radiation for L = O and L = L respectively.

Then,

$$\int_{E_o}^{E_L} \frac{dE}{E} = - \int_{0}^{L} KdL \quad (4.6)$$

$$E_L = E_o \cdot e^{-KL} \quad (4.7)$$

i.e. E_o is the energy of light when it just inters the surface. L is optical path length in water. Here L = AB + BC

or $$L = d(1 + \operatorname{cosec} E') \tag{4.8}$$

Therefore $$E_L = E_o \cdot e^{-Kd\,(1 + \operatorname{cosec} E')} \tag{4.9}$$

Energy received by the sensor will be sum of energy directly coming to sensor due to atmospheric scattering and refrected energy coming from water $E_o \cdot e^{-Kd(1 + \operatorname{cosec} E')}$.

If E_T be the total energy received by the sensor then

$$E_T = Ed + AE_o\, e^{-Kd(1 + \operatorname{cosec} E')} \tag{4.10}$$

where E_d = energy received directly through scattering by sensor and is constant for same conditions.

A = parameter depending upon state of atmosphere.

or $$E_T - E_d = AE_o\, e^{-Kd\,(1 + \operatorname{cosec} E')} \tag{4.11}$$

If E_x and E_y be the energy (Reflectance value) received by sensor for water depth x and y respectively, then

$$\frac{E_x - E_d}{E_y - E_d} = e^{-K\,(1 + \operatorname{cosec} E')\,(x - y)} \tag{4.12}$$

or $$x - y = \frac{\ln\left(\dfrac{E_x - E_d}{E_y - E_d}\right)}{-K(1 + \operatorname{cosec} E')} \tag{4.13}$$

If $y = 0$, then

$$\text{depth } x = \frac{\ln\left(\dfrac{E_x - E_d}{E_o - E_d}\right)}{-K\ (1 + \operatorname{cosec} E')} \qquad (4.14)$$

Where E_o is energy (Reflectance value) received by MSS, when water depth $\simeq$ 0.

In the above equation E_d, E_o and K are unknowns. For the determination of E_d, E_o and K, 30 points were taken on the toposheets which lie on the known depth countours. Latitudes and longitudes of all the points were calculated precisely. Their line number and pixel number and finally the corresponding reflectance value were read from CCT which is shown in Table 4.1. Now we have thirty equations and three unknowns. E_d, E_o and K were calculated by Least Square Method.

Solution by least square is given by the equation

$$X = -\ (A^T\ PA)^{-1}\ A^T\ PL$$

where A = coefficient matrix

= matrix of partial derivative of the function with respect to unknowns.

P = weight matrix.

Here weight matrix is taken as Unit Matrix.

$$L = (L_o - L_b)$$

TABLE : 4.1

POINTS ARE TAKEN ON 18m WATER DEPTH CONTOUR

Sl. No.	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLECTANCE VALUE
1.	15.48611	80.50000	1624	1037	28
2.	15.26361	80.25000	1978	662	28
3.	15.50000	80.50694	1617	1049	30
4.	15.25000	80.23833	1998	646	28
5.	15.60917	80.39472	1496	791	28
6.	15.32028	80.33500	1887	799	28
7.	15.17306	80.20694	2106	619	30
8.	15.13861	80.13917	2164	505	27
9.	15.02078	80.17028	2310	612	28
10.	16.13333	81.53333	579	2712	28
11.	15.93333	81.33333	882	2422	28
12.	15.73333	81.13333	1185	2131	27
13.	15.63333	80.66667	1542	1336	27
14.	15.40000	80.46667	1756	1015	31
15.	15.20000	80.26667	2059	720	28

TABLE : 4.1 (....CONTINUED)

POINTS ARE TAKEN ON 9m WATER DEPTH CONTOUR

Sl. No.	LATITUDE	LONGTITUDE	LINE No.	PIXEL No.	REFLECTANCE VALUE
1.	16.26667	81.53333	404	2655	37
2.	16.16667	81.33333	576	2322	37
3.	16.00000	81.26667	808	2268	36
4.	15.86667	81.13333	1010	2074	35
5.	15.66667	81.00000	1300	1908	37
6.	15.66667	80.73333	1353	1405	36
7.	15.66361	80.77667	1349	1488	36
8.	15.75000	80.37833	1315	702	35
9.	15.66333	80.91556	1321	1750	36
10.	15.79667	80.67556	1194	1242	37
11.	15.47028	80.35722	1686	779	37
12.	15.51472	80.48778	1602	1006	37
13.	15.36139	80.25000	1850	622	36
14.	15.25000	80.10972	2024	403	35
15.	15.02333	80.06778	2330	418	37

L_o = Matrix of computed value of x (depth) by assumed unknowns

L_b = Observed value of x (depth)

X = Correction Matrix for unknowns.

The expression can be write more simpler as

$$X = - (A^T A)^{-1} A^T L$$

$$X_a = [X_o + X]$$

where, X_a = Matrix of adjusted value of unknowns

X_o = Matrix of assumed value of unknowns.

For the assumed values of unknowns K, E_o and E_d, correction matrix X was determined as explained above and correction matrix was added to assumed values of unknowns. This process is repeated till we get very less variation in the correction matrix.

A program for least square method is given in Appendix - 4 and value of unknowns are as follows:

E_d = 23.61

E_o = 62.18

K = 0.057 m^{-1}

4.2 CALCULATION OF WATER DEPTH

Once the unknown E_d, E_o and K are determined, then it is very easy to calculate water depth at any point by equation 4.14, if reflectance value of that point is given.

4.3 DISCUSSION OF RESULTS

There are only two depth contours on the toposheets. For checking the accuracy of the work, 15 points on each of the contour lines were taken. Latitudes and Longitudes of all those points were calculated. Line numbers and pixel numbers of those points were calculated and reflectance values of all those points were read from CCT. Water depths of all those points were calculated by equation 4.13. The calculated depth of all thirty points are shown in Table 4.2. Then the difference of actual water depth taken from toposheet and calculated water depth is calculated for both the set of data 9 m and 18 m water depths separately.

Standard error (Se) and coefficient of correlation (r) are calculated as:

$$Se = \sqrt{\frac{\Sigma (Y_i - Y_{est}^2)}{N}}$$

$$r = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

TABLE :4.2

OR THE GIVEN DEPTH(Y)=18m

est=DEPTH CALCULATED

L. O.	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLE-CTANCE	Yest	Y-Yest
1.	15.50000	80.50694	1617	1047	28	18.1	-0.1
2.	15.52278	80.50000	1589	1026	28	18.1	-0.1
3.	15.68861	81.00000	1271	1898	27	20.3	-2.3
4.	15.61806	80.81056	1402	1507	28	18.1	-0.1
5.	15.60306	80.62750	1458	1233	28	18.1	-0.1
6.	15.32250	80.36806	1878	861	29	16.4	1.6
7.	15.21139	80.21972	2053	627	27	20.3	-2.3
8.	16.13333	80.60891	566	2838	28	18.1	-0.1
9.	15.83333	81.26667	1027	2339	29	16.4	1.6
10.	15.63333	80.60211	1555	1210	29	16.4	1.6
11.	15.43333	80.53333	1699	1126	28	18.1	-0.1
12.	15.33333	80.40211	1857	917	28	18.1	-0.1
13.	15.21139	80.21972	2053	627	27	20.3	-2.3
14.	15.62028	80.77677	1405	1507	28	18.1	-0.1
15.	15.25000	80.23833	1998	646	28	18.1	-0.1

TABLE :4.2(......CONTINUED)

FOR THE GIVEN DEPTH(Y)=9m

Yest=DEPTH CALCULATED

	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLE-CTANCE	Yest	Y-Yest
1.	15.75000	80.71500	1248	1336	37	8.8	0.2
2.	15.63639	80.85861	1335	1650	37	8.8	0.2
3.	15.73667	80.72972	1262	1369	36	9.5	-0.5
4.	15.68861	80.34472	1402	644	35	10.2	-1.2
5.	15.49528	80.34583	1655	747	37	8.8	0.2
6.	15.57944	80.54889	1505	1094	38	8.2	0.8
7.	15.42722	80.39472	1735	867	35	10.2	-1.2
8.	15.37000	80.17806	1853	482	37	8.8	0.2
9.	15.16139	80.08833	2144	400	37	8.8	0.2
0.	15.10222	80.05333	2229	358	38	8.2	0.8
1.	16.23333	81.68999	435	2795	35	10.2	-1.2
2.	15.90899	81.20888	909	2171	38	8.2	0.8
3.	16.26667	81.46667	418	2530	36	9.5	-0.5
4.	15.65083	80.77972	1365	1499	37	8.8	0.2
5.	15.39528	80.07611	1840	279	37	8.8	0.2

For the water depth of 9 m

$$r = -0.99902$$

$$Se = 0.684 \text{ m}$$

$$\sigma = 0.706 \text{ m}$$

For the water depth of 18 m

$$r = -0.995$$

$$Se = 1.255 \text{ m}$$

$$\sigma = 1.2828 \text{ m}$$

The negative sign shows the reciprocal relation. Here we find that standard error for 18 m water depth is more than that of 9 m water depth. It may be due to the reason that for same difference in reflectance values of deep and shallow water, the variation in water depth is more for deep water than for shallow water.

From the correlation analysis, it is clear that coefficient of correlation is about one, which shows that results obtained are quite satisfactory.

4.4 DRAWING OF WATER DEPTH CONTOUR

There are two methods for drawing contours

(a) Direct Method

(b) Indirect Method

In direct method of contouring, contour to be plotted is actually traced on the ground. We are concerned about only those points which lie on the contour. In the indirect method, some suitable guide points are selected and guide points need not necessarily be on the contours. The guide points serve as a basis for the interpolation of contours. In linear interpolation, it is assumed that water depth variation between two guide points is proportional to distance.

In the present work, indirect method of contouring was done. Total area was divided into small grids by drawing lines parallel to the longitudes and latitudes. The interval between the lines drawn parallel to latitude and longitude are kept 4 min and 2 min respectively. The latitudes and longitudes of all the corner points of the grids were calculated. The corresponding line numbers and pixel numbers were calculated by previously mentioned program. The reflectance values of all the pixels corresponding to grid corners were calculated and finally the depth of those points were calculated. The values are tabulated in Table 4.3. Points of equal depths (9 m and 18 m) were calculated by interpolation and contours were drawn. The contours what we obtained, is more or less same as the contours of the toposheet.

TABLE : 4.3

Sl. No.	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLECTANCE VALUE	WATER DEPTH
1.	16.33333	81.80000	262	3127	56	1.5
2.	16.30000	81.80000	306	3142	48	3.8
3.	16.26667	81.80000	350	3156	39	7.7
4.	16.23333	81.80000	394	3170	36	9.5
5.	16.20000	81.80000	437	3185	27	20.3
6.	16.16667	81.80000	481	3199	25	27.7
7.	16.13333	81.80000	525	3213	24	38.3
8.	16.30000	81.73333	320	3017	56	1.5
9.	16.26667	81.73333	364	3031	43	5.7
10.	16.23333	81.73333	407	3045	36	9.5
11.	16.20000	81.73333	451	3059	30	14.7
12.	16.16667	81.73333	495	3074	27	20.3
13.	16.13333	81.73333	538	3088	25	27.7
14.	16.10000	81.73333	582	3102	24	38.3
15.	16.30000	81.66667	333	2891	53	2.3
16.	16.26667	81.66667	377	2906	41	6.6
17.	16.23333	81.66667	421	2920	33	11.8
18.	16.20000	81.66667	465	2934	29	16.4
19.	16.16667	81.66667	508	2949	27	20.3
20.	16.13333	81.66667	552	2963	25	27.7
21.	16.10000	81.66667	596	2977	24	38.3
22.	16.33333	81.60000	303	2752	59	0.7
23.	16.30000	81.60000	347	2766	48	3.8
24.	16.26667	81.60000	391	2781	39	7.7
25.	16.23333	81.60000	435	2795	36	9.5
26.	16.20000	81.60000	478	2809	32	12.7
27.	16.16667	81.60000	522	2823	29	16.4
28.	16.13333	81.60000	566	2838	28	18.1
29.	16.10000	81.60000	609	2852	28	18.1
30.	16.06667	81.60000	653	2866	26	23.2
31.	16.03333	81.60000	697	2881	25	27.7
32.	16.00000	81.60000	741	2895	24	38.3
33.	16.33333	81.53333	317	2627	52	2.6
34.	16.30000	81.53333	361	2641	43	5.7
35.	16.26667	81.53333	404	2655	38	8.2
36.	16.23333	81.53333	448	2670	35	10.2
37.	16.20000	81.53333	492	2684	34	10.9
38.	16.16667	81.53333	536	2698	32	12.7
39.	16.13333	81.53333	579	2712	29	16.4
40.	16.10000	81.53333	623	2727	27	20.3
41.	16.06667	81.53333	667	2741	27	20.3
42.	16.03333	81.53333	711	2755	25	27.7
43.	16.00000	81.53333	754	2769	24	38.3
44.	16.33333	81.46667	331	2502	52	2.6

TABLE : 4.3 (....CONTINUED)

Sl. No.	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLECTANCE VALUE	WATER DEPTH
45.	16.30000	81.46667	374	2516	43	5.7
46.	16.26667	81.46667	418	2530	37	8.8
47.	16.23333	81.46667	462	2544	34	10.9
48.	16.20000	81.46667	506	2559	34	10.9
49.	16.16667	81.46667	549	2573	31	13.8
50.	16.13333	81.46667	593	2587	30	14.7
51.	16.10000	81.46667	637	2601	29	16.4
52.	16.06667	81.46667	680	2616	28	18.1
53.	16.03333	81.46667	724	2630	28	18.1
54.	16.00000	81.46667	768	2644	26	23.2
55.	15.96667	81.46667	812	2658	25	27.7
56.	15.93333	81.46667	855	2673	24	38.3
57.	16.33333	81.40000	344	2377	61	0.3
58.	16.30000	81.40000	388	2391	49	3.4
59.	16.26667	81.40000	432	2405	43	5.7
60.	16.23333	81.40000	475	2419	37	8.8
61.	16.20000	81.40000	519	2434	35	10.2
62.	16.16667	81.40000	563	2448	33	11.8
63.	16.13333	81.40000	607	2462	32	12.7
64.	16.10000	81.40000	650	2476	30	14.7
65.	16.06667	81.40000	694	2490	29	16.4
66.	16.03333	81.40000	738	2505	28	18.1
67.	16.00000	81.40000	781	2519	27	20.3
68.	15.96667	81.40000	825	2533	26	23.2
69.	15.93333	81.40000	869	2547	26	23.2
70.	15.90000	81.40000	913	2562	24	38.3
71.	16.30000	81.33333	401	2266	61	0.3
72.	16.26667	81.33333	445	2280	54	2.0
73.	16.23333	81.33333	489	2294	48	3.8
74.	16.20000	81.33333	533	2308	44	5.3
75.	16.16667	81.33333	576	2322	37	8.8
76.	16.13333	81.33333	620	2337	36	9.5
77.	16.10000	81.33333	664	2351	35	10.2
78.	16.06667	81.33333	708	2365	32	12.7
79.	16.03333	81.33333	751	2379	31	13.8
80.	16.00000	81.33333	795	2394	29	16.4
81.	15.96667	81.33333	839	2408	29	16.4
82.	15.93333	81.33333	882	2422	28	18.1
83.	15.90000	81.33333	926	2436	27	20.3
84.	15.86667	81.33333	970	2450	26	23.2
85.	15.83333	81.33333	1014	2465	25	27.7
86.	15.80000	81.33333	1057	2479	24	38.3
87.	16.26667	81.26667	459	2155	61	0.3
88.	16.23333	81.26667	502	2169	59	0.7
89.	16.20000	81.26667	546	2183	56	1.5
90.	16.16667	81.26667	590	2197	53	2.3
91.	16.13333	81.26667	634	2211	49	3.4
92.	16.10000	81.26667	677	2226	43	5.7
93.	16.06667	81.26667	721	2240	40	7.1
94.	16.03333	81.26667	765	2254	37	8.8
95.	16.00000	81.26667	808	2268	36	9.5
96.	15.96667	81.26667	852	2282	34	10.9

TABLE : 4.3

Sl. No.	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLECTANCE VALUE	WATER DEPTH
97.	15.93333	81.26667	896	2297	32	12.7
98.	15.90000	81.26667	940	2311	30	14.7
99.	15.86667	81.26667	983	2325	29	16.4
100.	15.83333	81.26667	1027	2339	28	18.1
101.	15.80000	81.26667	1071	2353	26	23.2
102.	15.76667	81.26667	1115	2367	26	23.2
103.	15.73333	81.26667	1158	2382	25	27.7
104.	15.70000	81.26667	1202	2396	24	38.3
105.	16.16667	81.20000	603	2072	59	0.7
106.	16.13333	81.20000	647	2086	55	1.7
107.	16.10000	81.20000	691	2100	52	2.6
108.	16.06667	81.20000	735	2114	48	3.8
109.	16.03333	81.20000	778	2129	44	5.3
110.	16.00000	81.20000	822	2143	43	5.7
111.	15.96667	81.20000	866	2157	41	6.6
112.	15.93333	81.20000	909	2171	38	8.2
113.	15.90000	81.20000	953	2185	36	9.5
114.	15.86667	81.20000	997	2199	33	11.8
115.	15.83333	81.20000	1041	2214	31	13.8
116.	15.80000	81.20000	1084	2228	30	14.7
117.	15.76667	81.20000	1128	2242	29	16.4
118.	15.73333	81.20000	1172	2256	28	18.1
119.	15.70000	81.20000	1216	2270	27	20.3
120.	15.66667	81.20000	1259	2284	26	23.2
121.	15.63333	81.20000	1303	2299	24	38.3
122.	15.96667	81.13333	879	2032	59	0.7
123.	15.93333	81.13333	923	2046	51	2.9
124.	15.90000	81.13333	967	2060	48	3.8
125.	15.86667	81.13333	1010	2074	43	5.7
126.	15.83333	81.13333	1054	2088	37	8.8
127.	15.80000	81.13333	1098	2102	36	9.5
128.	15.76667	81.13333	1142	2116	32	12.7
129.	15.73333	81.13333	1185	2131	29	16.4
130.	15.70000	81.13333	1229	2145	28	18.1
131.	15.66667	81.13333	1273	2159	27	20.3
132.	15.63333	81.13333	1316	2173	25	27.7
133.	15.60000	81.13333	1360	2187	24	38.3
134.	15.90000	81.06667	980	1934	58	1.0
135.	15.86667	81.06667	1024	1949	52	2.6
136.	15.83333	81.06667	1068	1963	46	4.5
137.	15.80000	81.06667	1111	1977	42	6.2
138.	15.76667	81.06667	1155	1991	39	7.7
139.	15.73333	81.06667	1199	2005	36	9.5
140.	15.70000	81.06667	1243	2019	32	12.7
141.	15.66667	81.06667	1286	2033	30	14.7
142.	15.63333	81.06667	1330	2047	28	18.1
143.	15.60000	81.06667	1374	2062	26	23.2
144.	15.56667	81.06667	1417	2076	25	27.7
145.	15.53333	81.06667	1461	2090	24	38.3
146.	15.73333	81.00000	1212	1880	46	4.5
147.	15.70000	81.00000	1256	1894	40	7.1
148.	15.66667	81.00000	1300	1908	36	9.5

TABLE : 4.3 (....CONTINUED)

Sl. No.	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLECTANCE VALUE	WATER DEPTH
149.	15.63333	81.00000	1343	1922	28	18.1
150.	15.60000	81.00000	1387	1936	25	27.7
151.	15.56667	81.00000	1431	1950	24	38.3
152.	15.70000	80.93333	1269	1768	44	5.3
153.	15.66667	80.93333	1313	1782	39	7.7
154.	15.63333	80.93333	1357	1796	31	13.8
155.	15.60000	80.93333	1401	1610	26	23.2
156.	15.56667	80.93333	1444	1824	25	27.7
157.	15.53333	80.93333	1488	1839	24	38.3
158.	15.70000	80.86667	1283	1643	48	3.8
159.	15.66667	80.86667	1327	1657	46	4.5
160.	15.63333	80.86667	1370	1671	43	5.7
161.	15.60000	80.86667	1414	1685	37	8.8
162.	15.56667	80.86667	1458	1699	27	20.3
163.	15.53333	80.86667	1501	1713	25	27.7
164.	15.50000	80.86667	1545	1727	24	38.3
165.	15.70000	80.80000	1296	1517	48	3.8
166.	15.66667	80.80000	1340	1531	44	5.3
167.	15.63333	80.80000	1384	1545	38	8.2
168.	15.60000	80.80000	1427	1559	32	12.7
169.	15.56667	80.80000	1471	1573	27	20.3
170.	15.53333	80.80000	1515	1587	25	27.7
171.	15.50000	80.80000	1559	1601	24	38.3
172.	15.86667	80.73333	1091	1321	58	1.0
173.	15.83333	80.73333	1135	1335	52	2.0
174.	15.80000	80.73333	1178	1349	48	3.8
175.	15.76667	80.73333	1222	1363	43	5.7
176.	15.73333	80.73333	1266	1377	41	6.6
177.	15.70000	80.73333	1310	1391	39	7.7
178.	15.66667	80.73333	1353	1405	37	8.8
179.	15.63333	80.73333	1397	1419	36	9.5
180.	15.60000	80.73333	1441	1433	32	12.7
181.	15.56667	80.73333	1484	1447	30	14.7
182.	15.53333	80.73333	1528	1462	28	18.1
183.	15.50000	80.73333	1572	1476	27	20.3
184.	15.46667	80.73333	1616	1490	26	23.2
185.	15.43333	80.73333	1659	1504	25	27.7
186.	15.40000	80.73333	1703	1518	24	38.3
187.	15.86667	80.66667	1104	1196	58	1.0
188.	15.83333	80.66667	1148	1210	51	2.9
189.	15.80000	80.66667	1192	1224	48	3.8
190.	15.76667	80.66667	1235	1238	44	5.3
191.	15.73333	80.66667	1279	1252	39	7.7
192.	15.70000	80.66667	1323	1266	38	8.2
193.	15.66667	80.66667	1367	1280	36	9.5
194.	15.63333	80.66667	1410	1294	35	10.2
195.	15.60000	80.66667	1454	1308	34	10.9
196.	15.56667	80.66667	1498	1322	31	13.8
197.	15.53333	80.66667	1542	1336	29	16.4
198.	15.50000	80.66667	1585	1350	28	18.1
199.	15.46667	80.66667	1629	1364	27	20.3
200.	15.43333	80.66667	1673	1378	26	23.2

TABLE : 4.3 (.....CONTINUED)

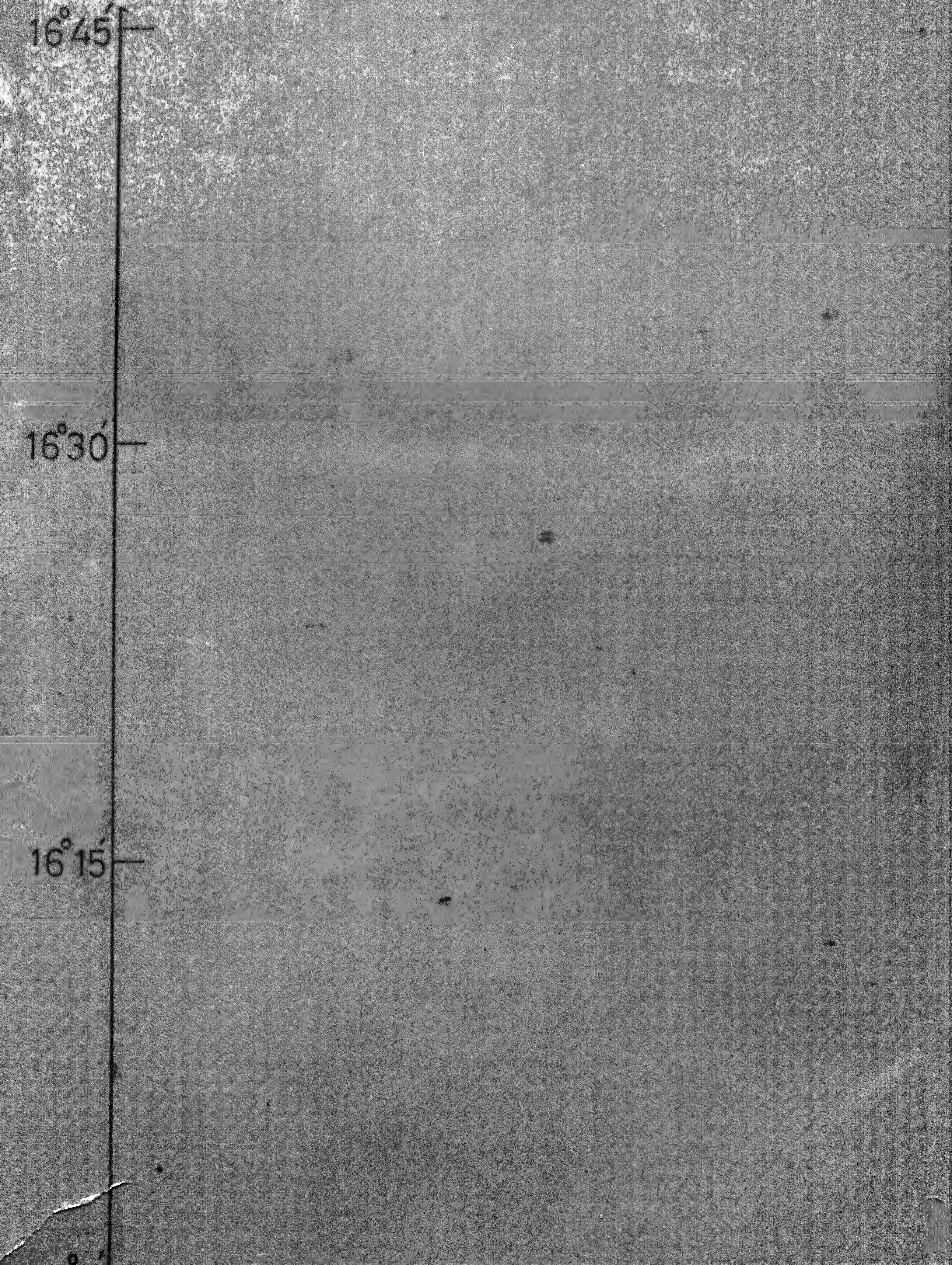
Sl. No.	LATITUDE	LONGITUDE	LINE No.	PIXEL NO.	REFLECTANCE VALUE	WATER DEPTH
201.	15.40000	80.65667	1715	1392	26	23.2
202.	15.36667	80.65667	1760	1406	25	27.7
203.	15.33333	80.65667	1304	1420	24	27.7
204.	15.86667	80.60000	1117	1070	59	3.7
205.	15.83333	80.60000	1151	1084	48	3.8
206.	15.80000	80.60000	1255	1098	43	5.7
207.	15.76667	80.60000	1249	1112	40	7.1
208.	15.73333	80.60000	1292	1126	37	8.8
209.	15.70000	80.60000	1335	1140	35	9.5
210.	15.66667	80.60000	1380	1154	35	9.5
211.	15.63333	80.60000	1424	1168	34	10.9
212.	15.60000	80.60000	1457	1182	33	11.8
213.	15.56667	80.60000	1511	1196	32	12.7
214.	15.53333	80.60000	1555	1210	30	14.7
215.	15.50000	80.60000	1599	1224	28	18.1
216.	15.46667	80.60000	1642	1238	27	20.3
217.	15.43333	80.60000	1585	1252	27	20.3
218.	15.40000	80.60000	1730	1266	25	23.2
219.	15.36667	80.60000	1774	1280	25	23.2
220.	15.33333	80.60000	1817	1294	25	27.7
221.	15.30000	80.60000	1851	1308	24	33.3
222.	15.83333	80.53333	1174	959	51	1.2
223.	15.80000	80.53333	1218	973	48	3.8
224.	15.76667	80.53333	1262	987	44	5.3
225.	15.73333	80.53333	1305	1001	39	7.7
226.	15.70000	80.53333	1349	1015	37	8.8
227.	15.66667	80.53333	1393	1029	35	10.2
228.	15.63333	80.53333	1437	1043	33	11.8
229.	15.60000	80.53333	1481	1056	32	12.7
230.	15.56667	80.53333	1524	1070	31	13.8
231.	15.53333	80.53333	1558	1084	30	14.7
232.	15.50000	80.53333	1512	1098	29	15.4
233.	15.46667	80.53333	1555	1112	29	15.4
234.	15.43333	80.53333	1599	1126	28	18.1
235.	15.40000	80.53333	1743	1140	27	20.3
236.	15.36667	80.53333	1787	1154	27	20.3
237.	15.33333	80.53333	1831	1168	26	23.2
238.	15.30000	80.53333	1874	1182	25	27.7
239.	15.26667	80.53333	1918	1196	25	27.7
240.	15.23333	80.53333	1952	1210	24	33.3
241.	15.80000	80.45667	1231	847	55	1.5
242.	15.76667	80.45667	1275	861	54	2.0
243.	15.73333	80.45667	1319	875	48	3.8
244.	15.70000	80.45667	1363	889	46	4.5
245.	15.66667	80.45667	1405	903	43	5.7
246.	15.63333	80.45667	1450	917	40	7.1
247.	15.60000	80.45667	1494	931	37	8.8
248.	15.56667	80.45667	1538	945	35	10.2
249.	15.53333	80.45667	1581	959	32	12.7
250.	15.50000	80.45667	1525	973	31	13.8
251.	15.46667	80.45667	1569	987	31	13.8
252.	15.43333	80.45667	1713	1001	30	14.7

TABLE : 4.3 (....CONTINUED)

Sl. No.	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLECTANCE VALUE	WATER DEPTH
253.	15.40000	80.46667	1756	1015	29	16.4
254.	15.36667	80.46667	1800	1028	28	18.1
255.	15.33333	80.46667	1844	1042	27	20.3
256.	15.30000	80.46667	1888	1056	26	23.2
257.	15.26667	80.46667	1931	1070	25	27.7
258.	15.23333	80.46667	1975	1084	25	27.7
259.	15.20000	80.46667	2019	1098	24	38.3
260.	15.76667	80.40000	1288	735	59	0.7
261.	15.73333	80.40000	1332	749	57	1.2
262.	15.70000	80.40000	1376	763	48	3.8
263.	15.66667	80.40000	1420	777	48	3.8
264.	15.63333	80.40000	1463	791	46	4.5
265.	15.60000	80.40000	1507	805	44	5.3
266.	15.56667	80.40000	1551	819	42	6.2
267.	15.53333	80.40000	1595	833	39	7.7
268.	15.50000	80.40000	1638	847	37	8.8
269.	15.46667	80.40000	1682	861	36	9.5
270.	15.43333	80.40000	1726	875	34	10.9
271.	15.40000	80.40000	1770	889	31	13.8
272.	15.36667	80.40000	1813	903	29	16.4
273.	15.33333	80.40000	1857	917	29	16.4
274.	15.30000	80.40000	1901	931	28	18.1
275.	15.26667	80.40000	1945	944	27	20.3
276.	15.23333	80.40000	1988	958	26	23.2
277.	15.20000	80.40000	2032	972	26	23.2
278.	15.16667	80.40000	2076	986	25	27.7
279.	15.13333	80.40000	2120	1000	24	38.3
280.	15.70000	80.33333	1389	638	57	1.2
281.	15.66667	80.33333	1433	652	54	2.0
282.	15.63333	80.33333	1477	666	48	3.8
283.	15.60000	80.33333	1520	679	48	3.8
284.	15.56667	80.33333	1564	693	44	5.3
285.	15.53333	80.33333	1608	707	42	6.2
286.	15.50000	80.33333	1652	721	39	7.7
287.	15.46667	80.33333	1695	735	37	8.8
288.	15.43333	80.33333	1739	749	34	10.9
289.	15.40000	80.33333	1783	763	32	12.7
290.	15.36667	80.33333	1827	777	31	13.8
291.	15.33333	80.33333	1870	791	31	13.8
292.	15.30000	80.33333	1914	805	29	16.4
293.	15.26667	80.33333	1958	819	28	18.1
294.	15.23333	80.33333	2002	832	27	20.3
295.	15.20000	80.33333	2045	846	26	23.2
296.	15.16667	80.33333	2089	860	26	23.2
297.	15.13333	80.33333	2133	874	25	27.7
298.	15.10000	80.33333	2177	888	25	27.7
299.	15.06667	80.33333	2220	902	24	38.3
300.	15.60000	80.26667	1534	554	57	1.2
301.	15.56667	80.26667	1577	568	52	2.6
302.	15.53333	80.26667	1621	582	46	4.5
303.	15.50000	80.26667	1665	595	43	5.7
304.	15.46667	80.26667	1709	609	40	7.1

TABLE : 4.3 (.....CONTINUED)

Sl. No.	LATITUDE	LONGITUDE	LINE No.	PIXEL No.	REFLECTANCE VALUE	WATER DEPTH
305.	15.43333	80.26667	1752	623	38	8.2
306.	15.40000	80.26667	1796	637	37	8.8
307.	15.36667	80.26667	1840	651	36	8.5
308.	15.33333	80.26667	1884	665	33	11.8
309.	15.30000	80.26667	1927	679	31	13.8
310.	15.26667	80.26667	1971	693	30	14.7
311.	15.23333	80.26667	2015	707	29	16.4
312.	15.20000	80.26667	2059	720	28	18.1
313.	15.16667	80.26667	2102	734	27	20.3
314.	15.13333	80.26667	2146	748	27	20.3
315.	15.10000	80.26667	2190	762	26	23.2
316.	15.06667	80.26667	2233	776	26	23.2
317.	15.03333	80.26667	2277	790	25	27.7
318.	15.00000	80.26667	2321	804	25	27.7
319.	15.43333	80.20000	1765	497	53	2.3
320.	15.40000	80.20000	1809	511	46	4.5
321.	15.36667	80.20000	1853	525	40	7.1
322.	15.33333	80.20000	1897	539	37	8.8
323.	15.30000	80.20000	1940	553	35	10.2
324.	15.26667	80.20000	1984	567	35	10.2
325.	15.23333	80.20000	2028	581	32	12.7
326.	15.20000	80.20000	2072	595	31	13.8
327.	15.16667	80.20000	2115	608	30	14.7
328.	15.13333	80.20000	2159	622	30	14.7
329.	15.10000	80.20000	2203	636	29	16.4
330.	15.06667	80.20000	2247	650	29	16.4
331.	15.03333	80.20000	2290	664	28	18.1
332.	15.00000	80.20000	2334	678	27	20.3
333.	15.36667	80.13333	1866	399	59	0.7
334.	15.33333	80.13333	1910	413	50	3.2
335.	15.30000	80.13333	1954	427	46	4.5
336.	15.26667	80.13333	1997	441	43	5.7
337.	15.23333	80.13333	2041	455	41	6.6
338.	15.20000	80.13333	2085	469	40	7.1
339.	15.16667	80.13333	2129	482	39	7.7
340.	15.13333	80.13333	2172	496	38	8.2
341.	15.10000	80.13333	2216	510	37	8.8
342.	15.06667	80.13333	2260	524	36	9.5
343.	15.03333	80.13333	2304	538	35	10.2
344.	15.00000	80.13333	2347	552	34	10.9
345.	15.13333	80.06667	2185	370	57	1.2
346.	15.10000	80.06667	2229	384	54	2.0
347.	15.06667	80.06667	2273	398	51	2.9
348.	15.03333	80.06667	2317	412	53	2.3


16°45′
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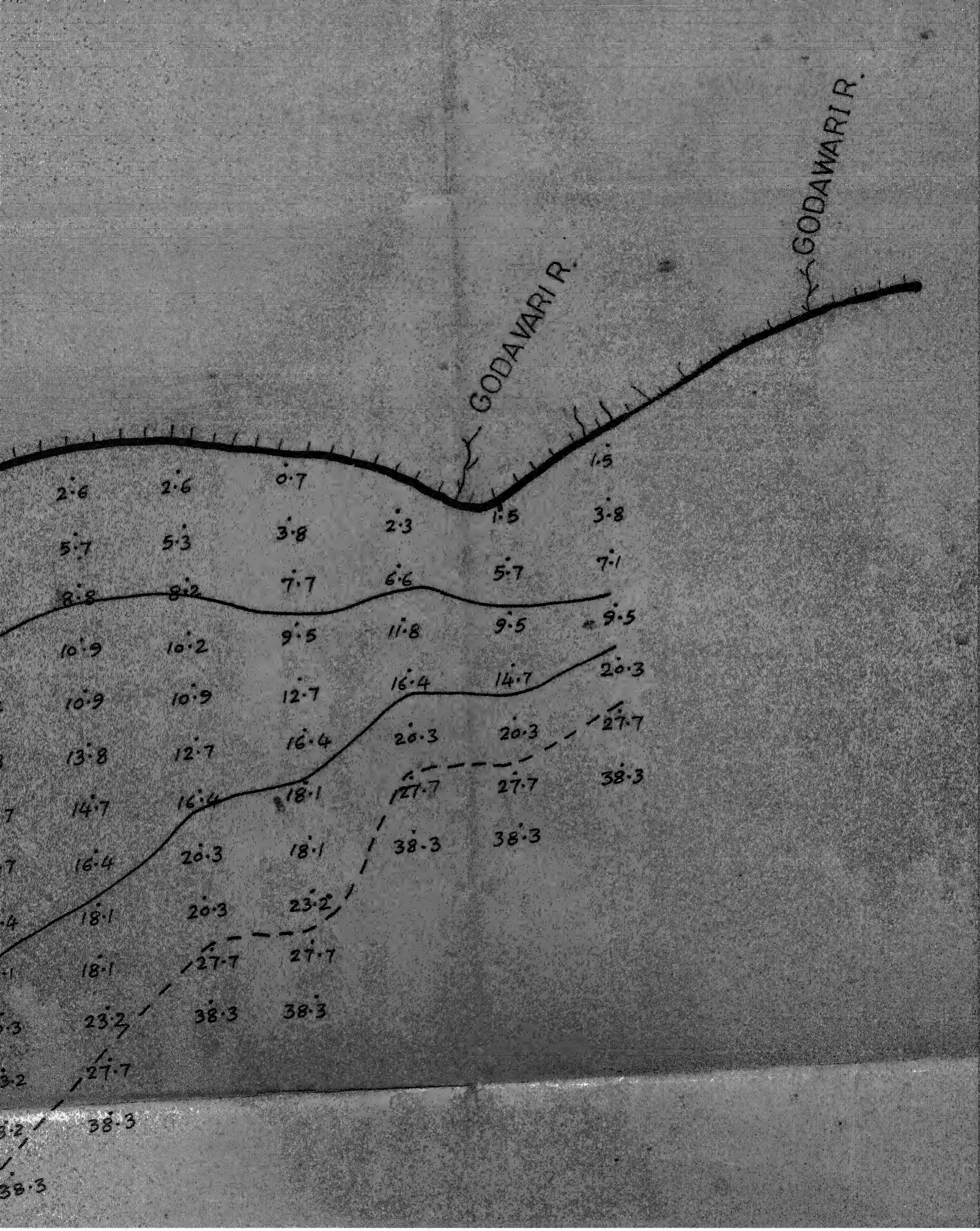
16°15′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GODAWARI R.
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8.8 8.2 7.7 6.6
10.9 10.2 9.5 11.8 9.5 9.5
10.9 10.9 12.7 16.4 14.7 20.3
13.8 12.7 16.4 20.3 20.3 27.7
14.7 16.4 18.1 27.7 27.7 38.3
16.4 20.3 18.1 38.3 38.3
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23.2 38.3 38.3
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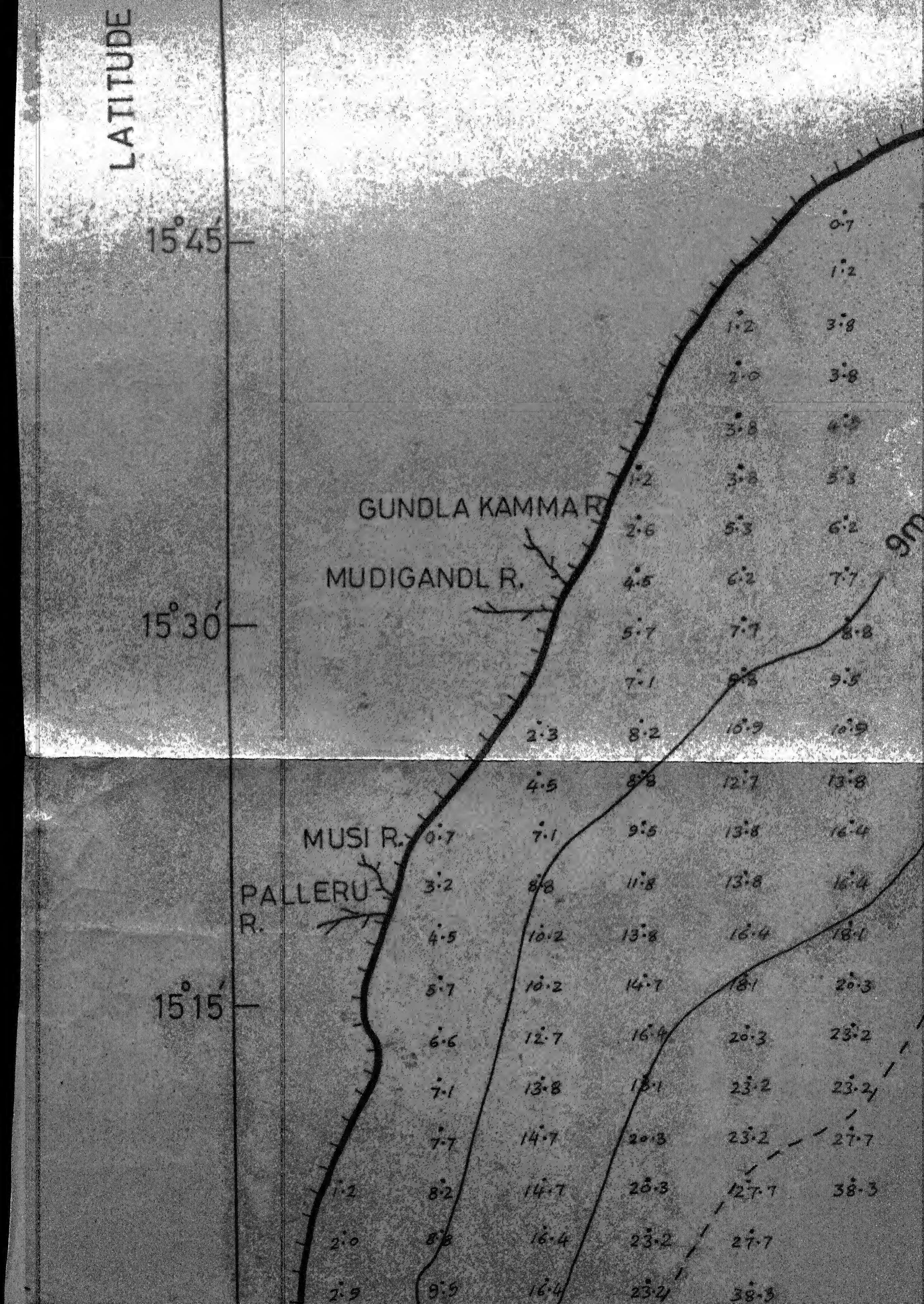
38.3
38.3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15°30'
15°15'
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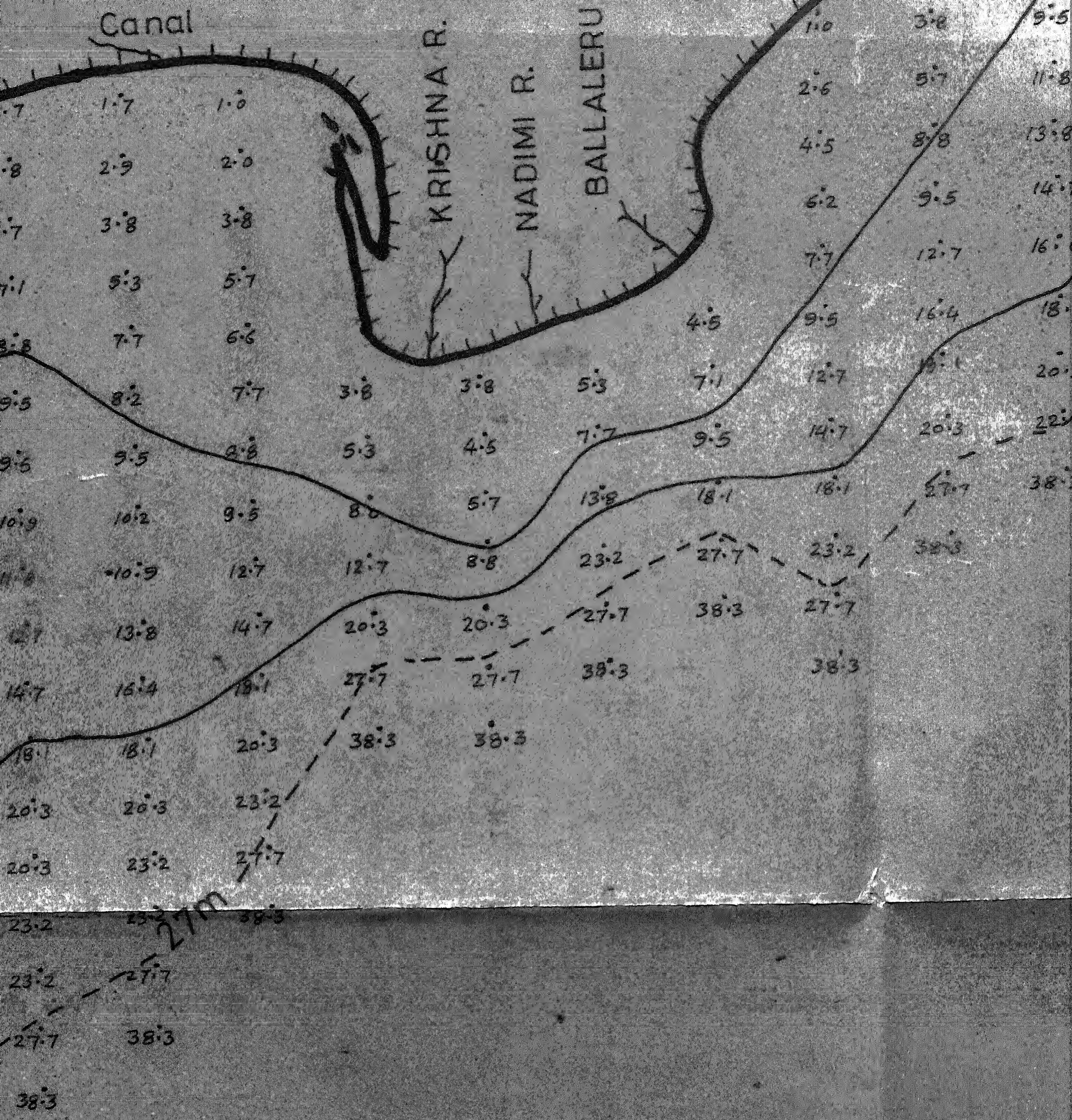
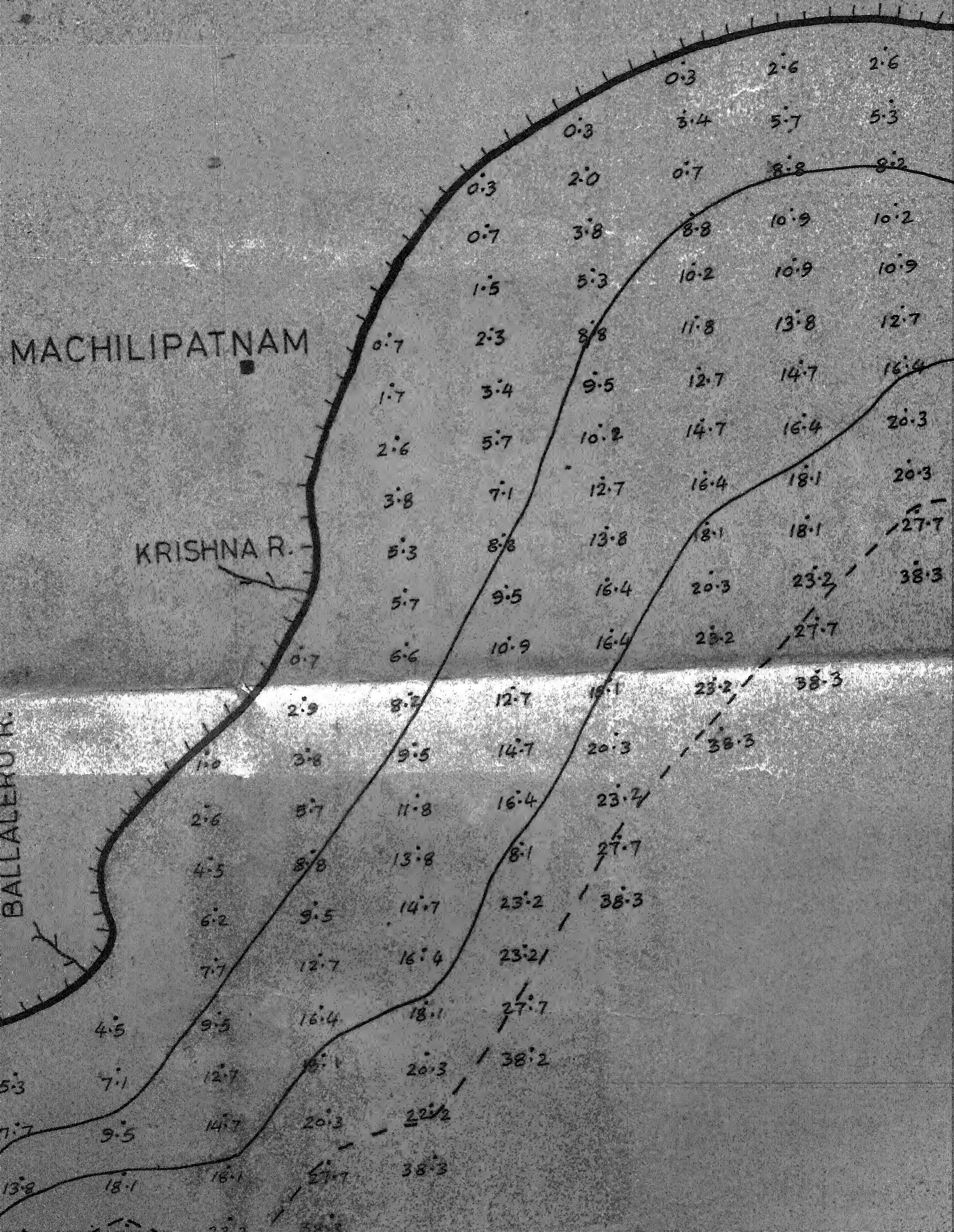
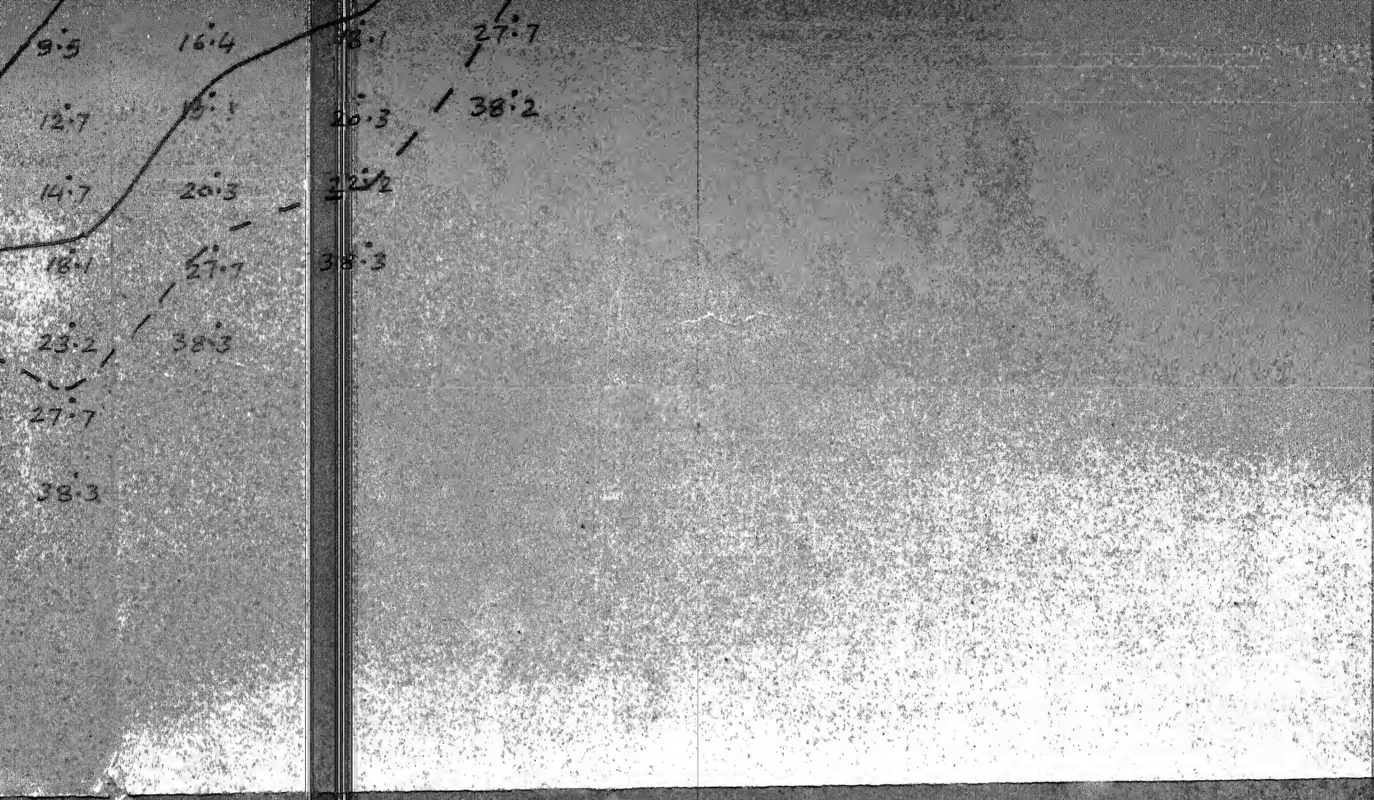
MUDIGANDL R.
MUSI R.
PALLERU R.



CONTOURS O


MACHILIPATNAM
KRISHNA R.
BALLALERU R.



ONTOURS OF WATER DEPTH OF ANDHRA

COASTAL REGION

(Machilipatnam)

0′ 81°15′ 81°30′

ONGITUDE →

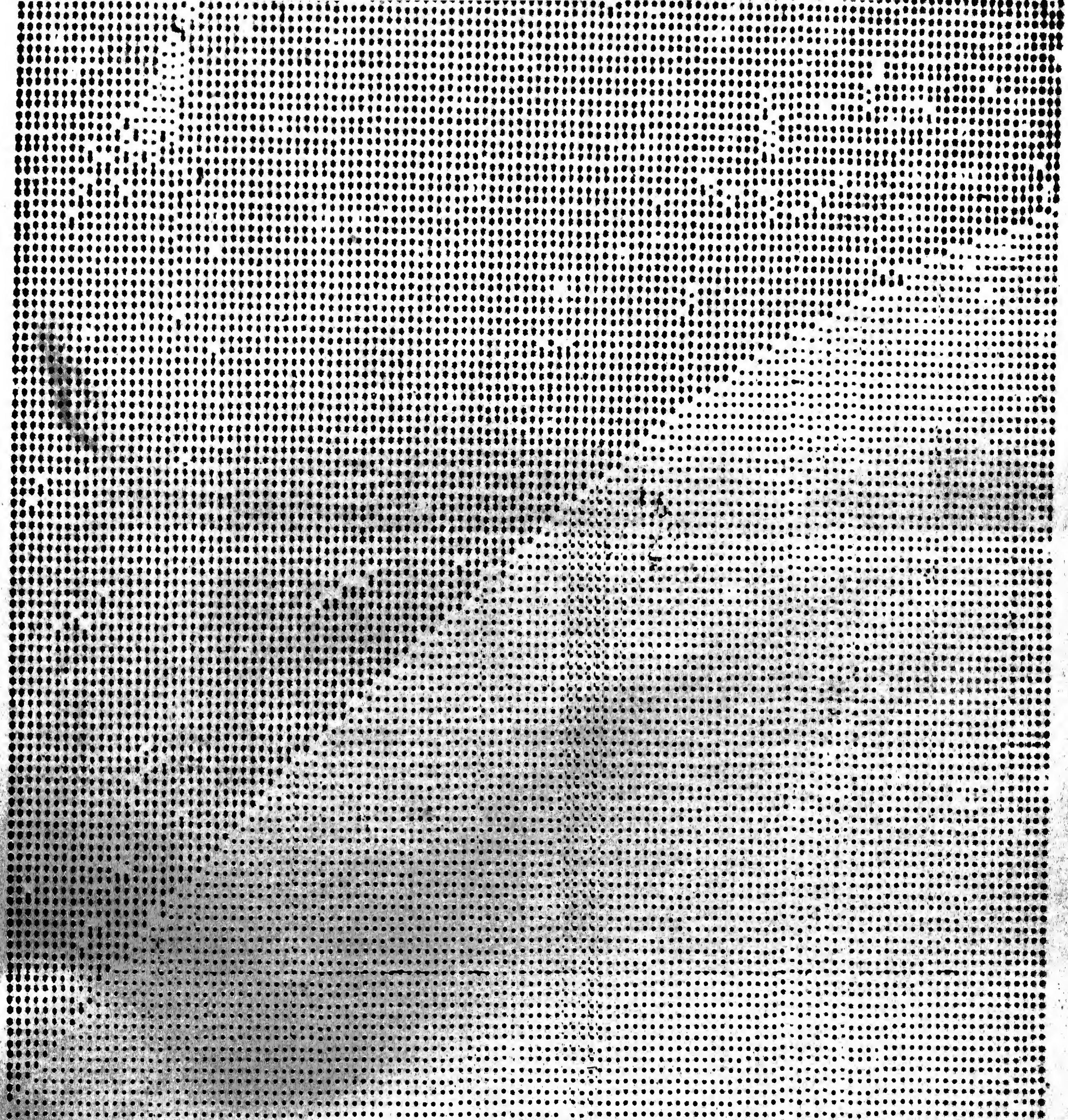


Fig. 4.2 : Map of Coastal Area

*→Land ..→ Water

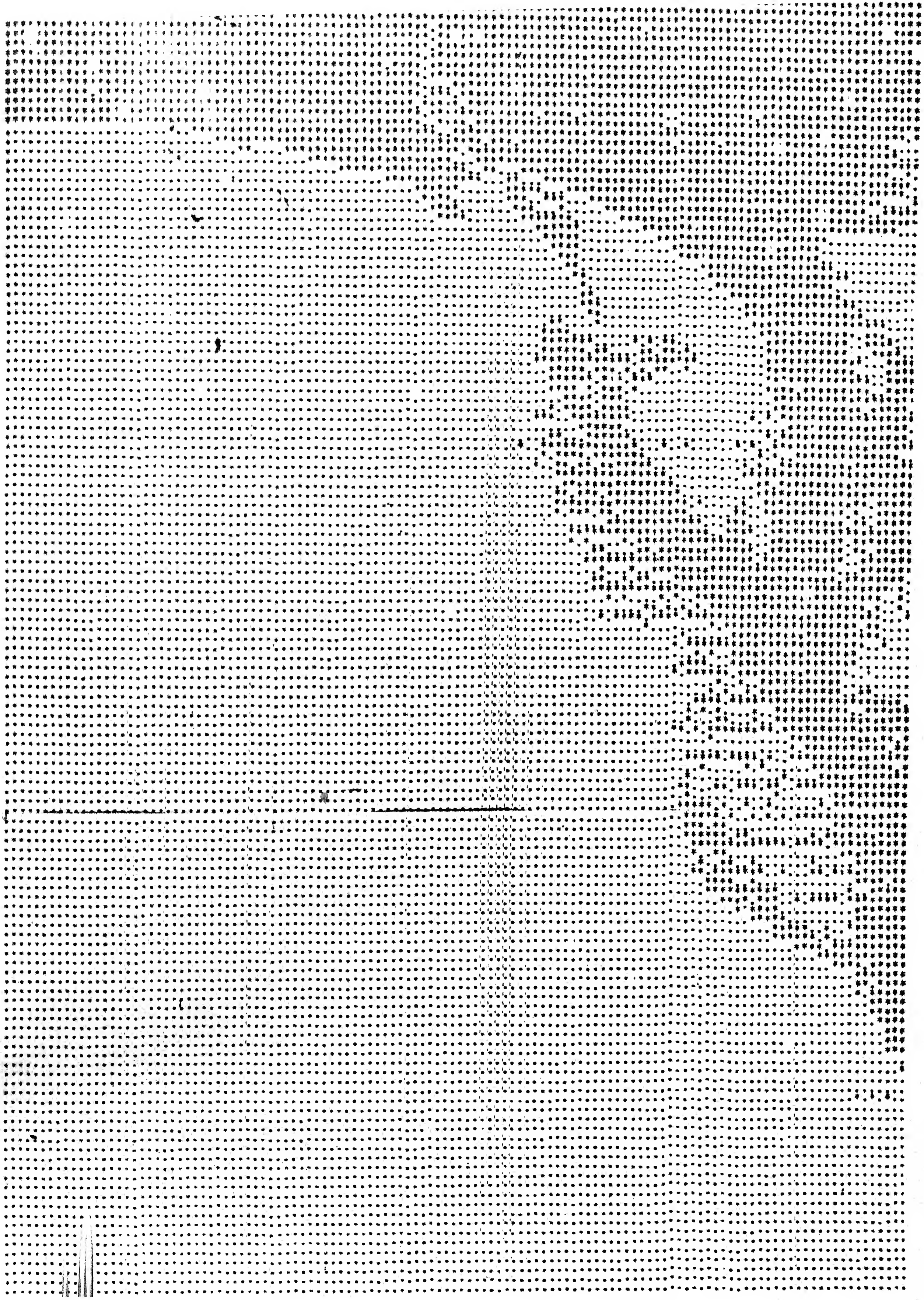


Fig. 4.3 : Map of Coastal Area
* → Land .. → water

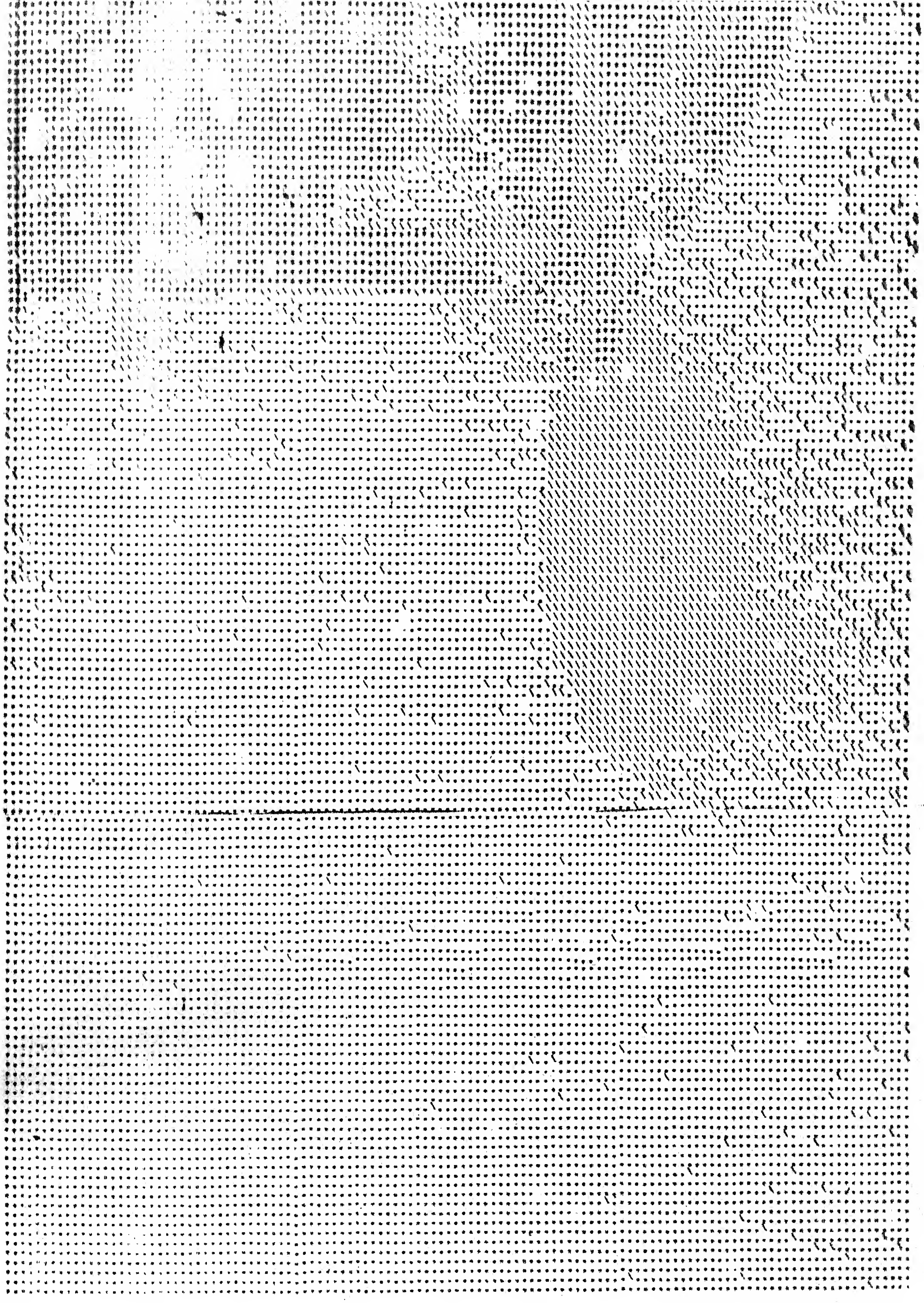


Fig. 4.4: Map of Coastal Area
* → Land \ → Water having suspended materials
.. → Clear Water

CHAPTER 5

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORK

5.1 CONCLUSIONS

The following conclusions are made after studying the Landsat data of the study area.

Bathymetry and coastal geomorphology can now be obtained from satellite data using Remote Sensing techniques specially in Band 1 (Landsat 4 and 5) where water is shallow and clear. The information obtained by this Remote Sensing technique is much time saving and cost effective compared to other conventional method like sounding machine, echo sounding, sonar, visible spectral range aerial photographic techniques. The scope of this technique becomes more, particularly in those area where no recent hydrographic surveys are available. This project introduce the newly developed technique of 'Bathymetry' i.e. delineation of coastal feature, water depth, water having suspended materials, et with the help of spectral reflectance by sensor.

The scope of present project enables us to obtain the preplanned position and to improve the internal relative position of the coastal features, in detecting features missed by earlier

surveyors, in improving delineation of features and to demarcate high water line and low water line.

Remote Sensing technique of Bathymetry is highly useful in areas of mobile seabed which are changing frequently like sandspits, at mouth of rivers, newly formed banks, islands to determined the rate of change of features and to update the information. It further helps in the study of coastal erosion, bank , channel, ground , submerged feature etc. The delineation of features by remote sensing is not only time saving and cost effective but also helps in developing new ports and sea routes.

In conclusion, it may be stated that present work helps in the field of hydrography as follows:

(a) To locate the high water line and low water line.

(b) To get water depth with good accuracy.

(c) To detect the character of coast and foreshore.

(d) To detect uncharted, mispositioned and submerged features which are hazardous to navigators.

(e) To define base line for territorial boundaries.

(f) To locate newly formed islands, banks, shoals etc.

(g) To show frequent change in ports, harbours, coastal areas of which immediate survey is not possible.

5.2 LIMITATIONS

The followings are requirements of this study:

1. The area should be cloud free.
2. Water should not have suspended materials because it can alter the reflectance value.
3. It should be shallow water.
4. There should not be change in refractive index of sea water. For our work, it is assumed that refrective index of sea water is same all over the sea.
5. The alignment of canals, drains, streams can be well interpreted but depth of water in canal, streams can not be found from Landsat Data.
6. Landsat data is found useful for regional study of large water bodies rather than small areas.
7. In general, ponds larger than 1 hectare and streams wider than 20 m are seen easily by Landsat imageries but individual objects less than 70 m can not be distinguished easily by Landsat data.

5.3 RECOMMENDATION FOR FUTURE WORK

1. The work can be further extended so that water depth can be predicted for deeper water.
2. If water depth is calculated keeping in mind that refrective

index of sea water is changing from place to place, we can get better result.

3. In this project, contouring was done for clear water. One may extend this for water having suspended materials.

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```
C                         APPENDIX : 1
C                         ------------


C     ******************************************************************
C          FILE NAME : MAN.FOR
C          PROGRAM TO CONNVERT THE GEOGRAPHICAL COORDINATE
C          TO ITS CONICAL ORTHOMORPHIC COORDINA  X  &  Y
C          THE CONSTANTS ARE VALID FOR STUDY AREA ONLY.
C     ******************************************************************

      IMPLICIT DOUBLE PRECISION(A-H,K-Z)
      DIMENSION LAT (150),LONG(150),LATRAD(150)
      LANGO=79.8428899
      LATO=14.753744122*3.1415921/180.0
      A=6377277.6
      ELLIP=1.0/300.8
      ELLIP=ELLIP*ELLIP
      SIN=DSIN(LATO)
      SINSQ=SIN*SIN
      DENOM=(1.0-(ELLIP*SINSQ))
      NO=A/(DSQRT(DENOM))
      RO=NO*((1.0-ELLIP)/DENOM)
      P=NO*(DCOS(LATO)/DSIN(LATO))
      RM=DSQRT(RO*NO)
      READ(21,*)II
      DO 100 I=1,II
      READ(21,*)DEG1,MIN1,SEC1,DEG2,MIN2,SEC2
      LAT(I)=DEG2+MIN2/60.0+SEC2/3600.0
      LONG(I)=DEG1+MIN1/60.0+SEC1/3600.0
      LATRAD(I)=LAT(I)*3.1415926/180.0
      LONGDF=LONG(I)-LANGO
      GAMMA=LONGDF*SIN
      GAMMA=GAMMA*3.1415926/180.0
      M=RM*((LATRAD(I)-LATO))
      M1=M**3/(6.0*RO*NO)
      TAN=DSIN(LATO)/DCOS(LATO)
      M2=M1*((M*TAN)/(4.0*NO))
      M11=M+M1+M2
      X=(P-M11)*DSIN(GAMMA)
      GAMMA=GAMMA/2.0
      Y=M11+X*(DSIN(GAMMA)/DCOS(GAMMA))
      WRITE(23,10) LAT(I),LONG(I), X,Y
100   CONTINUE
10    FORMAT(5X,F10.6,2X,F10.6,2X,'X=',F23.12,5X,'Y=',F23.15/)
      STOP
      END
```

```
C
C                          APPENDIX : 2
                           -------------

C     ************************************************************
C         FILE NAME : LINPIX.FOR
C         THIS PROGRAM CONVERTS THE LATITUDE AND LONGITUDE OF A GIVE
C         POINT ON THE EARTH'S SURFACE TO ITS LINE NUMBER AND PIXEL
C         NUMBER ON THE IMAGERY AFTER CONVERSION TO CONICAL ORTHOMOR
C         COORDINATE.
C         THE CONSTANTS ARE VALID FOR THE STUDY AREA ONLY.
C     ************************************************************

      IMPLICIT DOUBLE PRECISION(A-H,K-Z)
      DIMENSION LAT(150),LONG(150),LATRAD(150)
      LONGO=79.8428899
      LATO=14.753744122*3.1415926/180.0
      A=6377277.6
      ELLIP=1.0/300.8
      ELLIP=ELLIP*ELLIP
      SIN=DSIN(LATO)
      SINSQ=SIN*SIN
      DENOM=1.0-ELLIP*SINSQ
      NO=A/DSQRT(DENOM)
      RO=NO*((1.0-ELLIP)/DENOM)
      P=NO*(DCOS(LATO)/DSIN(LATO))
      RM=DSQRT(RO*NO)
      READ(56,*)II
      DO 100 I=1,II
      READ(56,*)DEG1,MIN1,SEC1,DEG2,MIN2,SEC2
      LAT(I)=DEG2+MIN2/60.0+SEC2/3600.0
      LONG(I)=DEG1+MIN1/60.0+SEC1/3600.0
      LATRAD(I)=LAT(I)*3.1415926/180.0
      LONGDF=LONG(I)-LONGO
      GAMMA=LONGDF*SIN
      GAMMA=GAMMA*3.1415926/180.0
      M=RM*(LATRAD(I)-LATO)
      M1=M**3/(6.0*RO*NO)
      TAN=DSIN(LATO)/DCOS(LATO)
      M2=M1*(M*TAN/(4.0*NO))
      M11=M+M1+M2
      X=(P-M11)*DSIN(GAMMA)
      GAMMA=GAMMA/2.0
      Y=M11+X*(DSIN(GAMMA)/DCOS(GAMMA))
      A1=-14.20582983283600
      B1=54.56466373351859
      C1=X-75232.55343041057980
      A2=-76.75741701113998
      B2=-11.08114531048586
      C2=Y-184829.92507817511000
      X1=(B2*C1-B1*C2)/(A1*B2-A2*B1)
      ILIN=X1+0.5
      ILIN1=ILIN*4
      Y2=(A2*C1-A1*C2)/(A2*B1-A1*B2)
      IPIX=Y2+0.5
      WRITE(22,1001)LAT(I),LONG(I),ILIN,ILIN1,IPIX
1001  FORMAT(6X,F12.8,2X,F12.8,2X,I4,2X,I4,2X,I4)
100   CONTINUE
10    FORMAT(5X,'LATITUDE=',F23.16,5X,'LONGITUDES=',F23.16/)
20    FORMAT(5X,79(1H=)//3X,'LATITUDE',5X,'LONGITUDE',//5X,79(1H-)/
      STOP
      END
```

```
C
C                          APPENDIX : 3
                           ------------

C     ****************************************************************
C         FILE NAME : CCT.FOR
C         PROGRAM TO READ AN IMAGE LINE OF THE CCT
C         THIS PROGRAM READS ONE RECORD OF CCT. THIS IS VALID AFTER
C         CONVERSION OF CCT FORMAT INTO DEC-10 COMPATIBLE.
C     ****************************************************************

      INTEGER OCT(1125),BT1,BT2,BT3,BT4,BT5
      OPEN(UNIT=53,DEVICE='DSK')
      OPEN(UNIT=50,DEVICE='DSK')
      OPEN(UNIT=45,DEVICE='DSK')
      OPEN(UNIT=20,DEVICE='MTA1',MODE='DUMP',RECORD SIZE=1125,DEN
     1='1600')
      NO=-3
      READ(20)OCT
      DO 1200 I=1,1125
      NO=NO+4
      BT1=OCT(I)/2**28
      BT2=(OCT(I)-BT1*2**28)/2**20
      BT3=(OCT(I)-BT1*2**28-BT2*2**20)/2**12
      BT4=(OCT(I)-BT1*2**28-BT2*2**20-BT3*2**12)/2**4
      WRITE(53,11)NO,BT1,BT2,BT3,BT4
11    FORMAT(5I5)
1200  CONTINUE
      CALL CONE
      CLOSE(UNIT=20,DEVICE='MTA1',MODE='DUMP',RECORD SIZE=1125,DE
     1SITY='1600')
      STOP
      END
      SUBROUTINE CONE
      DIMENSION NAT(25)
      COMMON NAT
      REWIND 53
      DO 101 I=1,225
      READ(53,10)(NAT(K),K=1,5)
      READ(53,10)(NAT(K),K=6,10)
      READ(53,10)(NAT(K),K=11,15)
      READ(53,10)(NAT(K),K=16,20)
      READ(53,10)(NAT(K),K=21,25)
      WRITE(50,21)NAT
21    FORMAT(25I5)
101   CONTINUE
10    FORMAT(5I5)
      RETURN
      END
```

APPENDIX : 4

```
*****************************************************************
      FILE NAME : LEAST.FOR
      PROGRAM TO FIND THE VALUE OF CONSTANT  E0, Ed & Vd  BY  LEAST
      SQUARE WITCH IS USED IN DEPTH FORMULA
*****************************************************************

      DIMENSION VX(10),X(10),AT(3,10),A(10,3),AL(10),R1(10),R2(10)
      DIMENSION X1(10)
      OPEN(UNIT=22,DEVICE='DSK',FILE='FOR22.DAT',ACCESS='SEQOU')
      OPEN(UNIT=21,DEVICE='DSK',FILE='FOR21.DAT',ACCESS='SEQIN')
      Y=-2.267
      V0=55
      VD=17
      CK=0.075
      DO 56 K=1,12
      VD=VD
      CK=CK
      V0=V0
      DO 10 I=1,10
      ICK=K
      IF(ICK.EQ.1)READ(21,*)X(I),VX(I)
      READ(21,*) X(I),VX(I)
      R1(I)=-ALOG((VX(I)-VD)/(V0-VD))/(Y*CK**2)
      R2(I)=(VX(I)-V0)/(Y*CK*(V0-VD)*(VX(I)-V0))
      R3(I)=-(VX(I)-VD)/(Y*CK*(V0-VD)*(VX(I)-VD))
      AL(I)=X(I)
      X1(I)=ALOG((VX(I)-VD)/(V0-VD))/Y*CK
      AL(I)=X1(I)-X(I)
      TYPE*,VX(I),X(I),R1(I),R2(I)
      TYPE*,AL(I)
      CONTINUE
      I=1
      DO 30 J=1,10
      AT(I,J)=R1(J)
      I=2
      DO 40 J=1,10
      AT(I,J)=R2(J)
      I=3
      DO 45 J=1,10
      AT(I,J)=R3(J)
      J=1
      DO 31 I=1,10
      A(I,J)=R1(I)
      J=2
      DO 41 I=1,10
      A(I,J)=R2(I)
      J=3
      DO 46 I=1,10
      A(I,J)=R3(I)
      TYPE*,((AT(I,J),I=1,3),J=1,10)
      TYPE*,((A(I,J),I=1,10),J=1,3)
      WRITE(22,*) (VX(I),X(I),R1(I),R2(I),I=1,10)
      WRITE(22,*) ((AT(I,J),I=1,3),J=1,10)
      WRITE(22,*) ((A(I,J),I=1,10),J=1,3)
      L=3
      M=10
      N=3
      CALL MULT(AT,A,B,L,M,N)
      N=3
      CALL INVERT(B,N)
```

```
L=3
M=3
N=10
CALL MULT(B,AT,C,L,M,N)
L=3
M=10
N=1
CALL MULT(C,AL,D,L,M,N)
D1=-D1
D2=-D2
D3=-D3
CK=CK+D1
VD=VD+D2
VO=VO+D3
WRITE(22,*) I, CK,VD,VO,D1,D2,D3
FORMAT(8X,'ITERATION NO=',2I/,8X,'CK=',F10.5/,8X,'VD=',F10.5/,
18X,'VO=',F10.5/,8X,'D1=',F10.5/,8X,'D2=',F10.5/,'D3=',F10.5)
TYPE*,D1,D2,D3
CONTINUE
STOP
END
SUBROUTINE FOR MULTIPLICATION OF MATRIX
SUBROUTINE MULT(R,S,T,L,M,N)
DIMENSION R(L,M),S(M,N),T(L,N)
DO 55 I=1,L
DO 55 J=1,N
SUM=0.0
DO 46 K=1,M
SUM=SUM+R(I,K)*S(K,J)
T(I,J)=SUM
RETURN
END
SUBROUTINE FOR INVERSE OF MATRIX
SUBROUTINE INVERT(A,N)
DIMENSION A(50,50),INDEX(50)
DO 113 I=1,N
INDEX(I)=0
AMAX=-1.0
DO 115 I=1,N
IF(INDEX(I))115,116,115
TEMP=ABS(A(I,I))
IF(TEMP-AMAX)115,115,117
ICOL=I
AMAX=TEMP
CONTINUE
IF(AMAX)118,118,119
INDEX(ICOL)=1
PIVOT=A(ICOL,ICOL)
A(ICOL,ICOL)=1.0
PIVOT=1.0/PIVOT
DO 110 J=1,N
A(ICOL,J)=A(ICOL,J)*PIVOT
DO 121 I=1,N
IF(I-ICOL)122,121,122
TEMP=A(I,ICOL)
A(I,ICOL)=0.00
DO 123 J=1,N
A(I,J)=A(I,J)-A(ICOL,J)*TEMP
CONTINUE
GO TO 114
RETURN
END
```

```
C                       APPENDIX : 5
C                       ------------

C   ***********************************************************************
C        FILE NAME : PART.FOR
C        THIS PROGRAM READS A RECORD OF THE CCT BUT THE
C        OUTPUT WILL BE ONLY A PART OF IT.
C   ***********************************************************************

         INTEGER OCT(1125),BT1,BT2,BT3,BT4,BYTE(4000)
         OPEN(UNIT=53,DEVICE='DSK')
         OPEN(UNIT=50,DEVICE='DSK',FILE='PART')
         OPEN(UNIT=20,DEVICE='MTA1',MODE='DUMP',RECORD SIZE=1125,
         1DENSITY='1600')
         READ(20)OCT
         J=1
         DO 1200 I=1,1125
         BT1=OCT(I)/2**28
         BYTE(J)=BT1; J=J+1
         BT2=(OCT(I)-BT1*2**28)/2**20
         BYTE(J)=BT2;J=J+1
         BT3=(OCT(I)-BT1*2**28-BT2*2**20)/2**12
         BYTE(J)=BT3; J=J+1
         BT4=(OCT(I)-BT1*2**28-BT2*2**20-BT3*2**12)/2**4
         BYTE(J)=BT4; J=J+1
1200     CONTINUE
         CLOSE(UNIT=20,DEVICE='MTA1',MODE='DUMP',RECORD SIZE=1125,
         1DENSITY='1600')
C
C        TO WRITE THE DATA
         WRITE(50,*)(BYTE(K),K=2721,3440,6)
         STOP
         END
```

```
C                              APPENDIX : 6
C                              ------------

C    ***************************************************************
C        FILE NAME : DENSITY.FOR
C        THIS IS AN INTERACTIVE PROGRAM FOR MAPPING THE
C        SURFACE FEATUURES BASED ON THE DENSITY SLICING METHOD
C        PROGRAM IS FOR EFFECTIVE FOR 10 CLASSES
C        THERE IS NO LIMIT ON THE LENGTH OF THE INPUT BUT
C        THE NUMBER OF PIXELS PER LINE SHOULD NOT EXCEED  960
C    ***************************************************************

        INTEGER IPIX(960),INTMAT(960),GREY(10)
        INTEGER CONTOR(10),INTVL(10),UPLIM(10),LOWLIM(10)
        OPEN(UNIT=25,DEVICE='DSK',FILE='INPUT')
        OPEN(UNIT=6,DEVICE='DSK',FILE='MAP1')
        OPEN(UNIT=7,DEVICE='DSK',FILE ='MAP2')
        OPEN(UNIT=8,DEVICE='DSK',FILE='MAP3')
        OPEN(UNIT=9,DEVICE='DSK',FILE='MAP4')
        OPEN(UNIT=10,DEVICE='DSK',FILE='MAP5')
        OPEN(UNIT=11,DEVICE='DSK',FILE='MAP6')
        OPEN(UNIT=12,DEVICE='DSK',FILE='MAP7')
        OPEN(UNIT=13,DEVICE='DSK',FILE='MAP8')
C
C       INTERACTION BEGINS
C
        TYPE 10
10      FORMAT('    ALL TERMINAL INPUT IS FORMAT FREE',//,
        18X,'TYPE IN THE NUMBER OF CLASSES FOR SLICING')
        ACCEPT *,NCLASS
        TYPE 20
20      FORMAT(8X,'TYPE IN CHARACTERS FOR REPRESENTATION
        1 OF THE CLASSES')
        ACCEPT 25,(GREY(I),I=1,NCLASS)
25      FORMAT(10A1)
C
C       TO GET THE CONTOUR LEVEL AND INTERVAL OF EACH CLASS
C       FROM TERMINAL
C
        DO 30 I=1,NCLASS
        TYPE 40,I
40      FORMAT(8X,'TYPE IN THE CONTOUR LEVEL AND INTERVAL',I2)
        ACCEPT *,CONTOR(I),INTVL(I)
        UPLIM(I)=CONTOR(I)+INTVL(I)
        LOWLIM(I)=CONTOR(I)-INTVL(I)
30      CONTINUE
        TYPE 50
50      FORMAT(8X,'TYPE IN THE LENGTH AND BREADTH OF INPUT')
        ACCEPT *,NLINE,NPIX
        TYPE 55
55      FORMAT(8X,'TYPE IN THE NUMBER OF OUPUT FILES')
        ACCEPT *,NOUTFL
C
C
C       INTERACTION ENDS.
```

Program DENSTY.FOR contd..

```
C
C       TO INITIALISE THE INTERMEDIATE MATRIX INTMAT
C
        DO 65 I=1,NPIX
65      INTMAT(I)=' '
C
C       TO READ AND CLASSIFY THE INPUT DATA
C
        ILOOP=0
60      CONTINUE
        READ(25,*)(IPIX(I),I=1,NPIX)
        ILOOP=ILOOP + 1
        DO 70 I=1,NPIX
        DO 70 J=1,NCLASS
        IF((IPIX(I).LE.UPLIM(J)).AND.(IPIX(I).GE.LOWLIM(J)))
       1INTMAT(I)=GREY(J)
70      CONTINUE
C
C       To transfer the results from INTMAT to output files
C       for getting the line printer map.
C
        NUNIT=6
        M=1
        N=M+119
        DO 80 I=1,NOUTFL
        WRITE(NUNIT,90)(INTMAT(J),J=M,N)
90      FORMAT(120A1)
        NUNIT=NUNIT+1
        M=N+1
        N=M+119
80      CONTINUE
        IF (ILOOP.LT.NLINE) GOTO 60
        STOP
        END
```